Thoughts on SRTM and Permissible Shortcuts in the LOS/Viewshed Algorithm

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Based on Two Talks

- **Terrain Fingerprints: ASPRS Denver, May 2004 (published in conference proceedings)**
- **MICRODEM UAV Route Analysis: Boeing Progress Report, Seattle, July 2004**

Terrain Fingerprints: Statistical Analysis of DEMs

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asprs 70 THE IMAGING & GEOSPATIAL INFORMATION SOCIETY

Terrain modeling, the practice of ground-surface quantification, is an amalgam of Earth science, mathematics, engineering, and computer science. The discipline is known variously as geomorphometry, morphometry, terrain analysis, or quantitative geomorphology.

(Pike, 2002)

Terrain Fingerprint Builds on Earlier Work

Richard Pike (USGS):

- 1988, Mathematical Geology, vol.20, no.5, p.491-512.
- 2000, Progress in Physical Geography, vol.24, no.1, p.1-20.

Ian Evans (Durham, UK):

- 1980, Zeitschrift für Geomorphologie N.F. Suppl. 36, p.274-295.
- 1998, *in* Landform monitoring, modelling and analysis, J.Wiley, p. 119-138.

Methodology

- 8 DEM series from NGA, NASA, and USGS
- Divide into 2.5’ by 2.5’ blocks (~500,000 in continental US)
- Compute 35 parameters for each block
- Store grids with results
- Graphs and tables to compare results

Table 1. Eight DEM series used to compute Terrain Fingerprints for the US

DEM Series	Spacing	Tiles	Files	Size	US Coverage
SRTM-3[1]	3”	--	--	--	100%
USGS 250K	3”	1º	955	989 MB[4]	100%
ASTER[2]	30 m	--	2610	20.2 GB[4]	5%
SRTM-1	1”	1.25º	673	25.3 GB	100%
USGS 24K Level 1[3]	30 m	7.5’	18,177	9.1 GB[4]	34%
USGS 24K Level 2[3]	30 m	7.5’	28,611		53%
USGS 24K Level 1[3]	10 m	7.5’	1622		3%
NED[3]	1”	1.25º	669	24.5 GB	100%

[1] SRTM-3 subsampled from SRTM-1.
[2] ASTER data complete coverage available summer 2003.
[3] 24K DEM was complete sample when it was available from USGS servers, summer 2001, and includes some duplicate coverage.
[4] Compressed sizes

150 GB drive = $100

Few days to process larger data sets

Programs Used

- http://www.usna.edu/Users/oceano/pguth/website/microdemdown.htm
- freeware

Terrain Fingerprint™
Digital Elevation Model data creation, enhancement, diagnostics, and repair using our Terrain Fingerprint™ database.

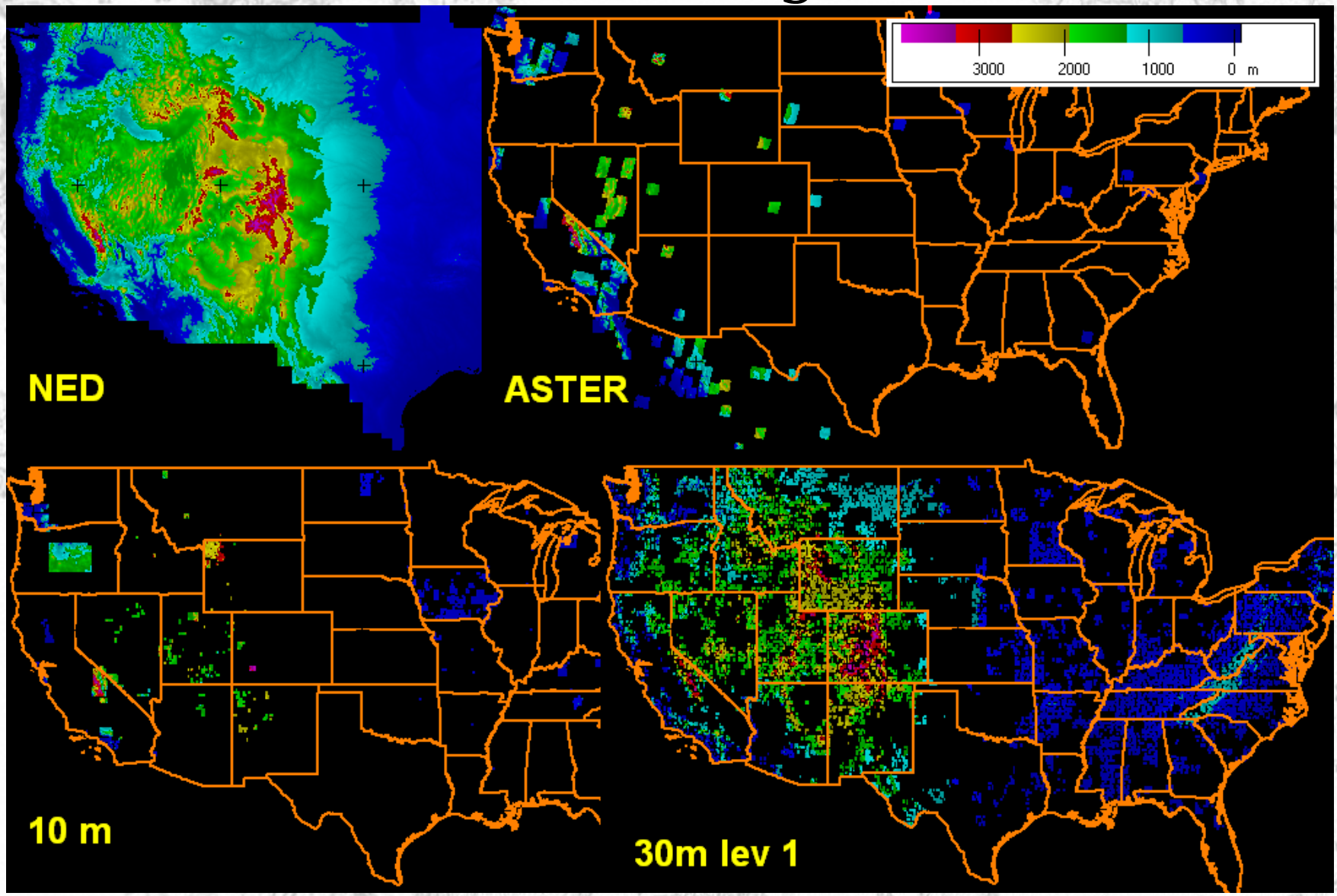
- http://www.nsiworldwide.com/
- free demo

Atlas--35 Variables

Point and region variables

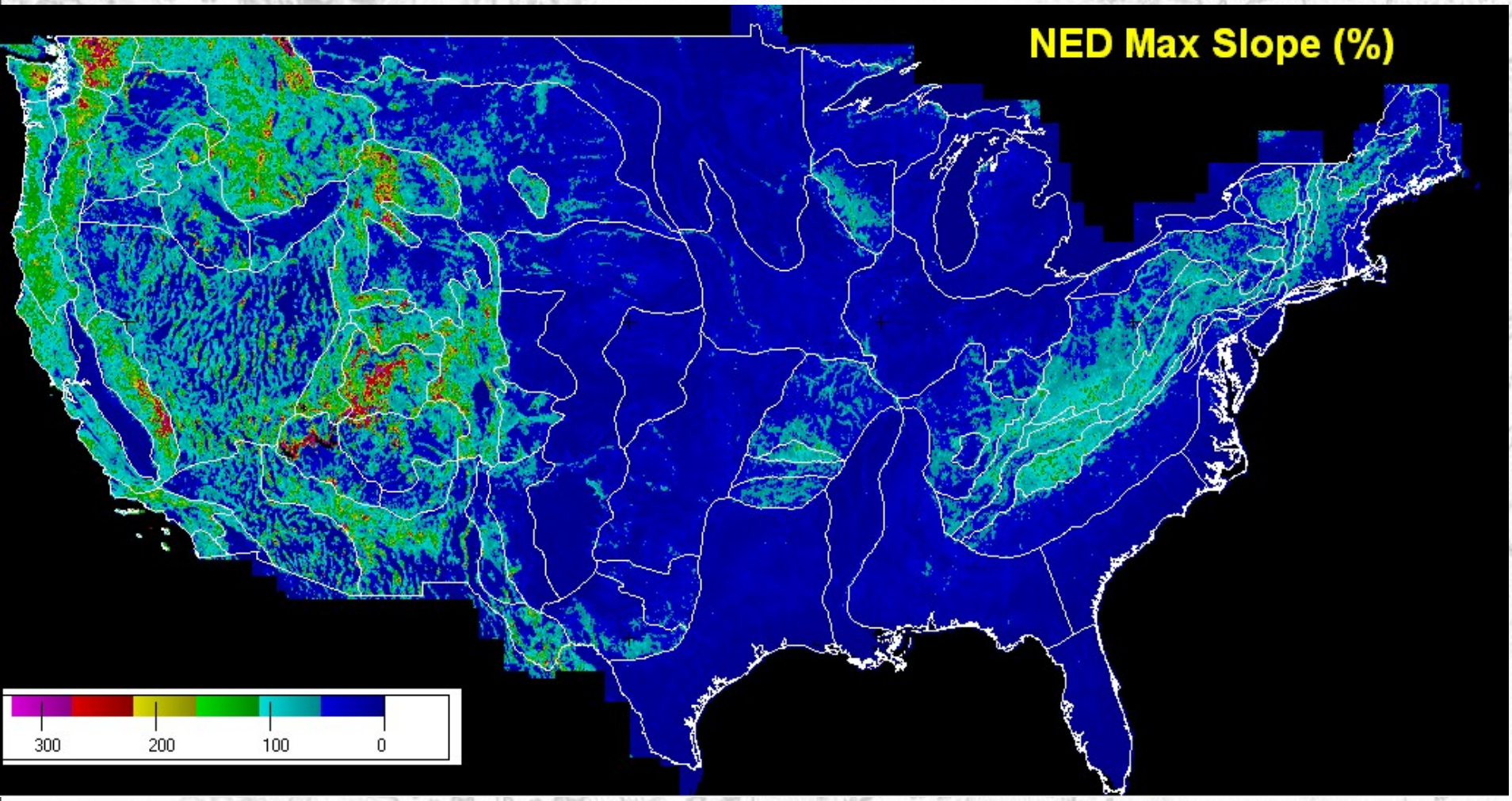
- Four distribution moments (average, standard deviation, skewness, kurtosis)
  - Elevation
  - Slope in percent and degrees
  - Plan and profile curvature
- Gamma from variogram in four directions
- Relief
- Roughness
- Hypsometric integral
- Terrain Organization (eigenvector analysis flatness, organization, direction)
- DEM Quality Measures
  - Contour ghosts
  - Maximum slope
  - Queen’s aspect

Average Elevation—Shows Data Coverage



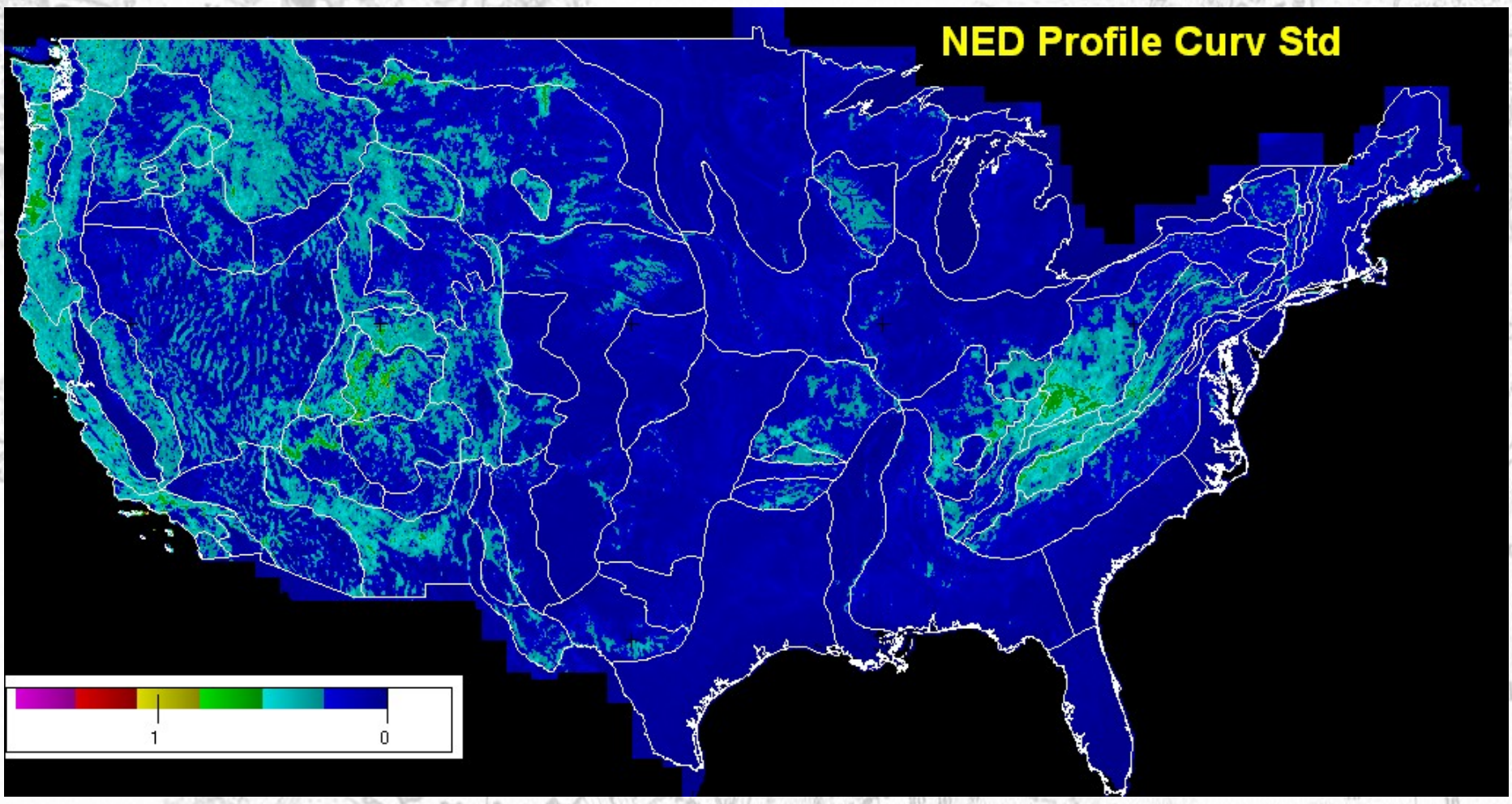
10 m coverage not random; includes data for several

Max Slope Important Quality Control Variable for DEMs

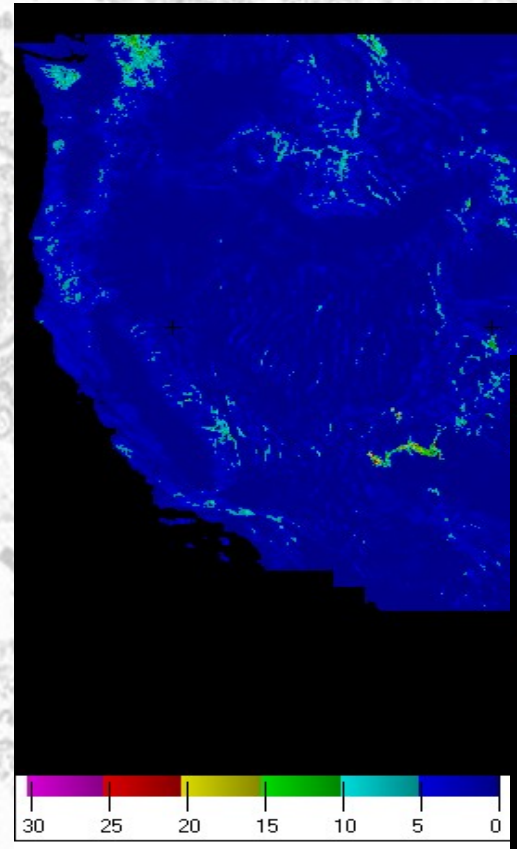


Fenneman Provinces outlined in v

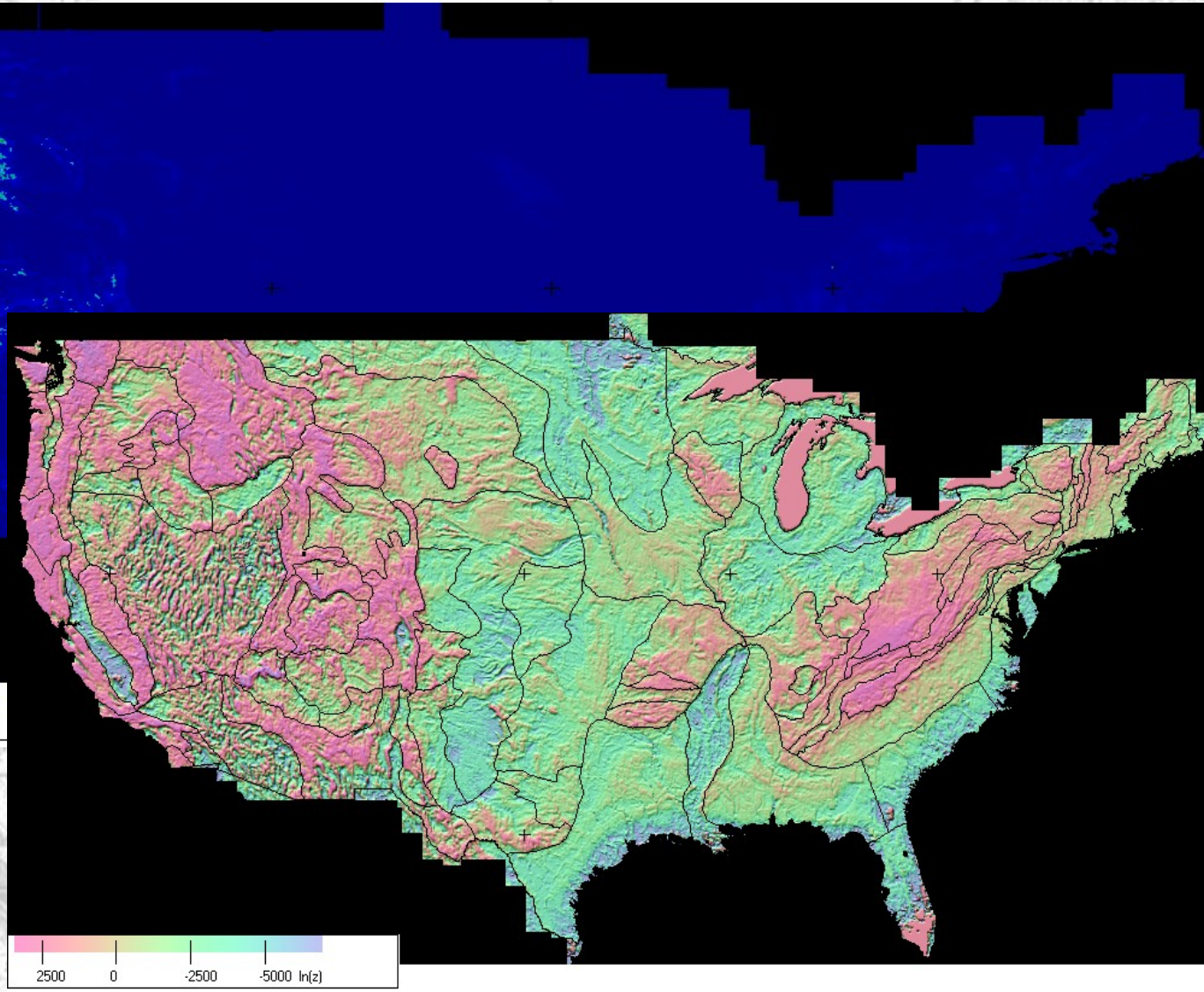
NED Profile Curvature Std Dev



Fenneman Provinces outlined in whit

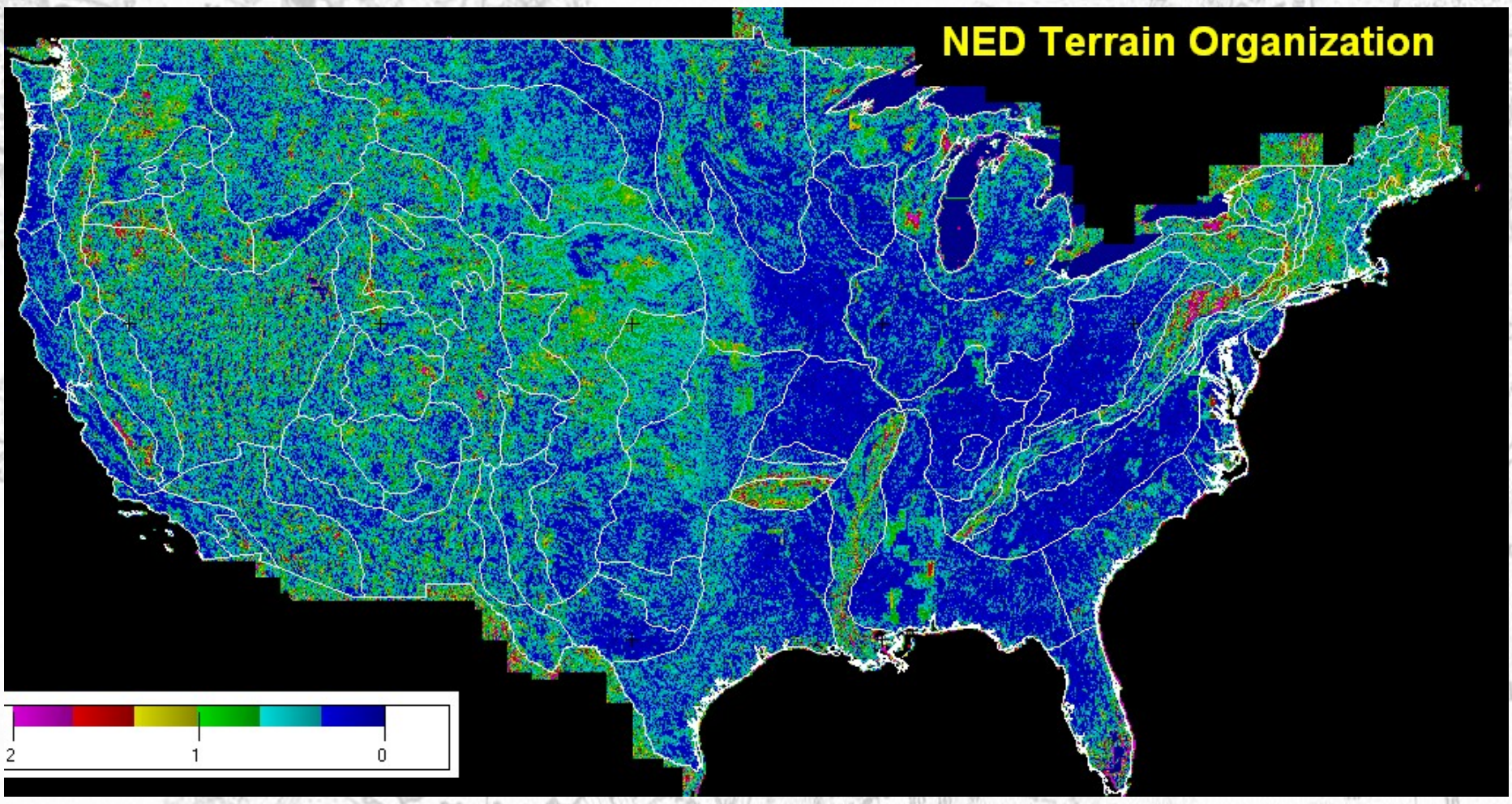


GAMMA_NS in meters for the 1" NED dataset. Only the steepest parts of the American West stand out, especially the Grand Canyon and the North



Logarithmic transformation applied to the GAMMA_NS data. The boundaries of the Fenneman physiographic provinces show that variations in this parameter correspond with accepted boundaries.

NED Terrain Organization



Fenneman Provinces outlined in white

280 grids: 35 parameters, 8 series

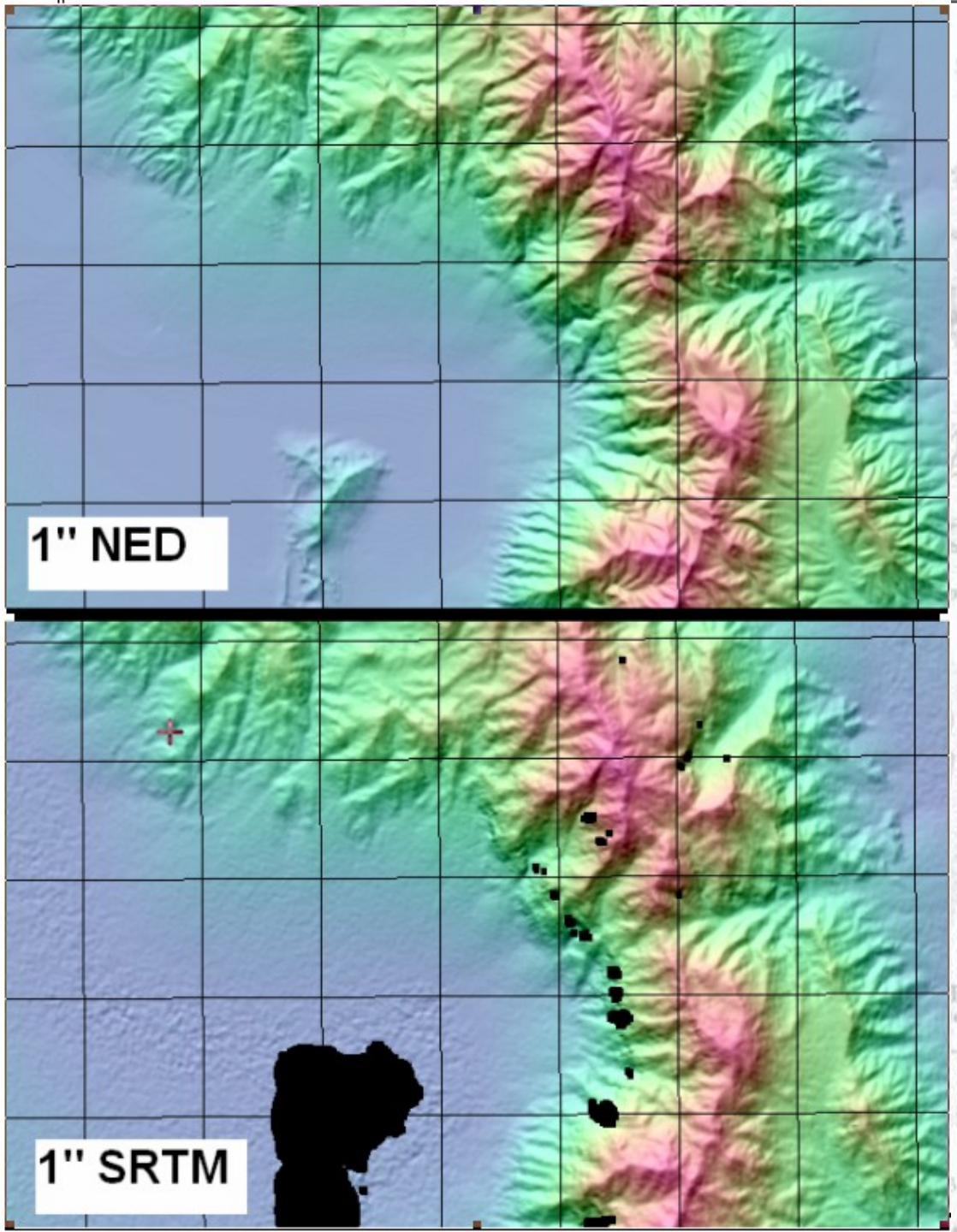
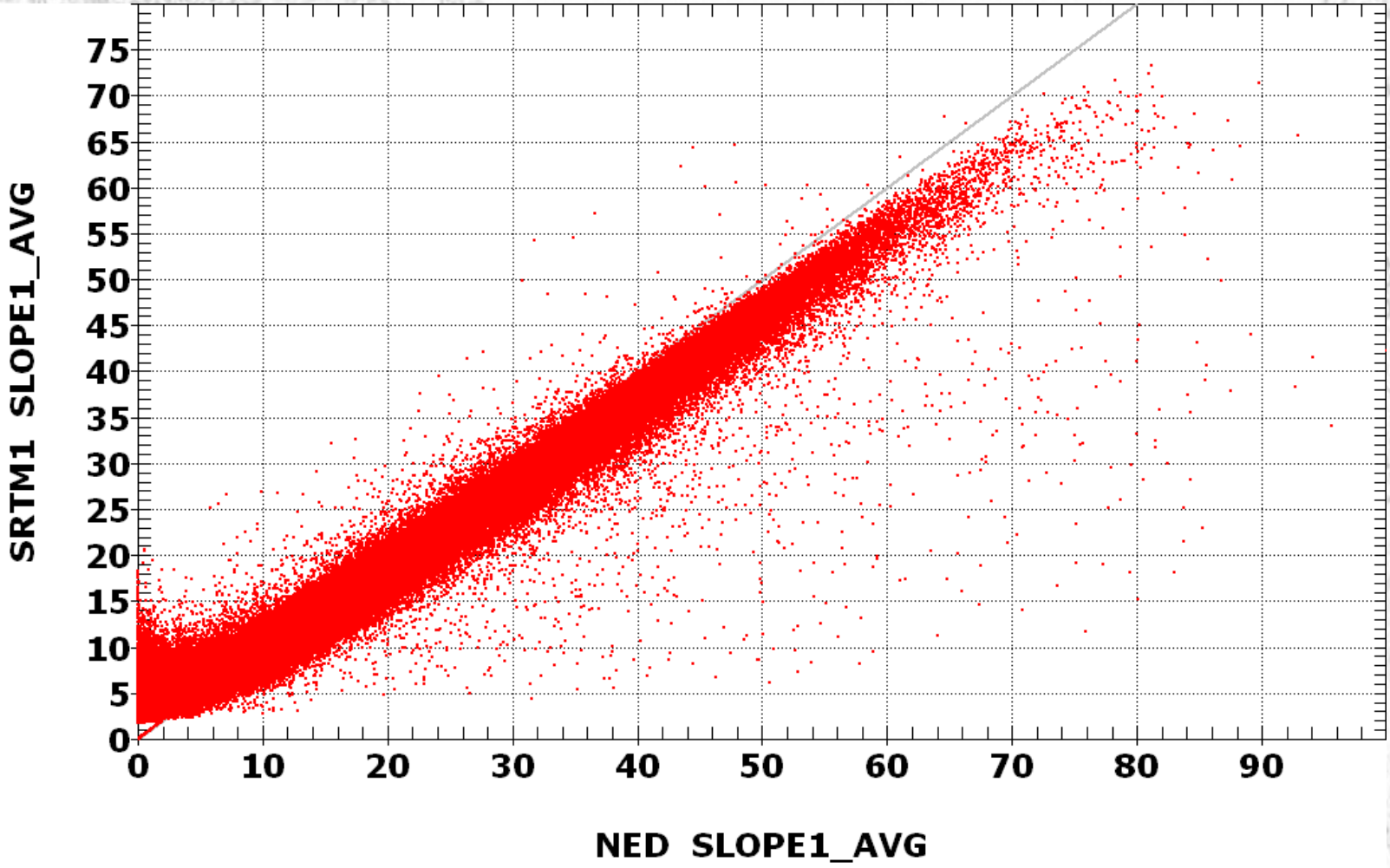


Figure 3. Comparison of NED and SRTM for the southern Last Chance Range. Note holes in SRTM data, both in steep areas along mountain front and the entire 200 m tall Eureka Valley Sand Dune. Also note speckle in the valley floor in the SW corner of the SRTM DEM, and the general smoothing of mountains in SRTM data.



500,000 points; outliers emphasized visually

SRTM is too steep for gentle topography (radar speckle)

SRTM is not steep enough for steep topography

Table 2. SLOPE1_AVG Correlation Coefficients

	10M	NED	30M2	30M1	ASTER	SRTM1	250K	SRTM3
10M		0.9985	0.9976	0.9873	0.9022	0.9867	0.9620	0.9788
NED	0.9985		0.9989	0.9872	0.8135	0.9840	0.9639	0.9803
30M2	0.9976	0.9989		0.9872	0.8545	0.9862	0.9704	0.9816
30M1	0.9873	0.9872	0.9872		0.7873	0.9810	0.9644	0.9762
ASTER	0.9022	0.8135	0.8545	0.7873		0.8222	0.8200	0.9138
SRTM1	0.9867	0.9840	0.9862	0.9810	0.8222		0.9736	0.9913
250K	0.9620	0.9639	0.9704	0.9644	0.8200	0.9736		0.9826
SRTM3	0.9788	0.9803	0.9816	0.9762	0.9138	0.9913	0.9826	

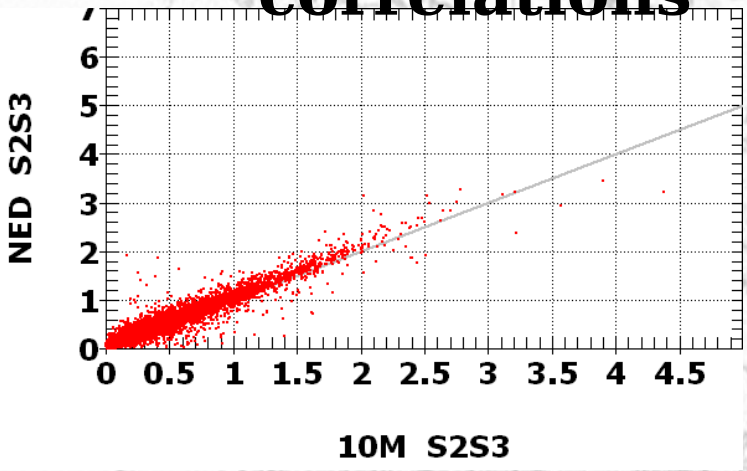
ASTER DEMs have lowest correlations—least similarity to other DEMs

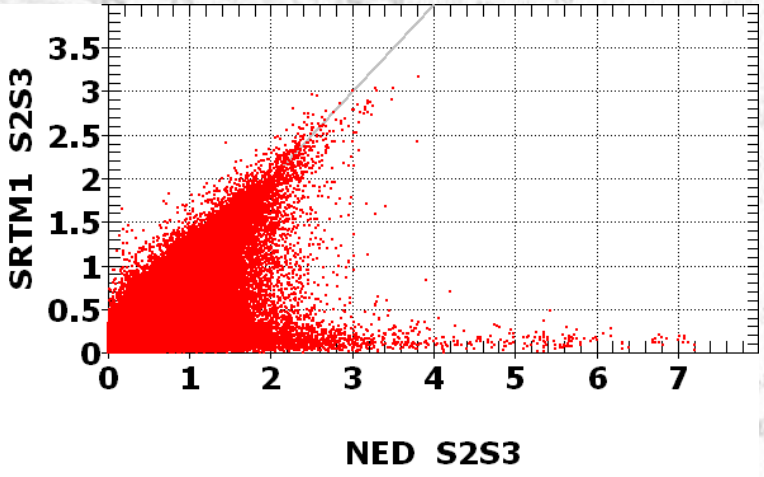
Table 3. S2S3 (Organization) Correlation Coefficients

	10M	NED	30M2	30M1	ASTER	SRTM1	250K	SRTM3
10M		0.8671	0.9509	0.7244	0.4993	0.7272	0.4848	0.7690
NED	0.8671		0.8917	0.6437	0.4538	0.6324	0.4077	0.6517
30M2	0.9509	0.8917		0.5756	0.4364	0.6055	0.3769	0.6438
30M1	0.7244	0.6437	0.5756		0.4997	0.5612	0.3950	0.5534
ASTER	0.4993	0.4538	0.4364	0.4997		0.7300	0.2525	0.5808
SRTM1	0.7272	0.6324	0.6055	0.5612	0.7300		0.2828	0.8706
250K	0.4848	0.4077	0.3769	0.3950	0.2525	0.2828		0.4122
SRTM3	0.7690	0.6517	0.6438	0.5534	0.5808	0.8706	0.4122	

n

ASTER, 250K lowest correlations



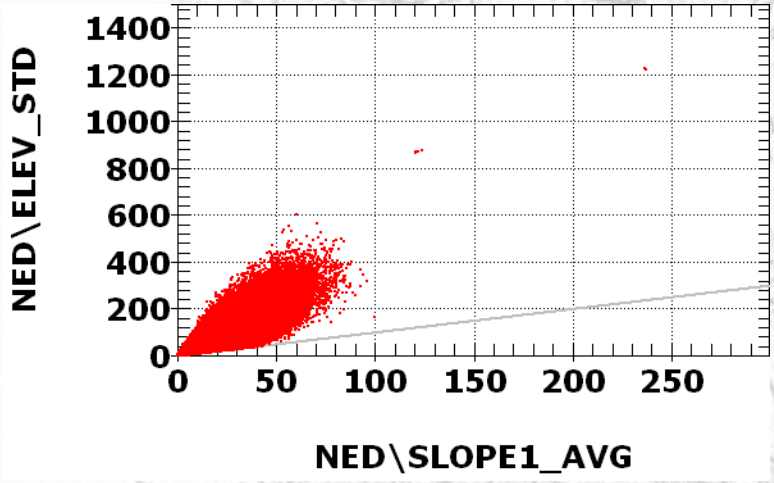


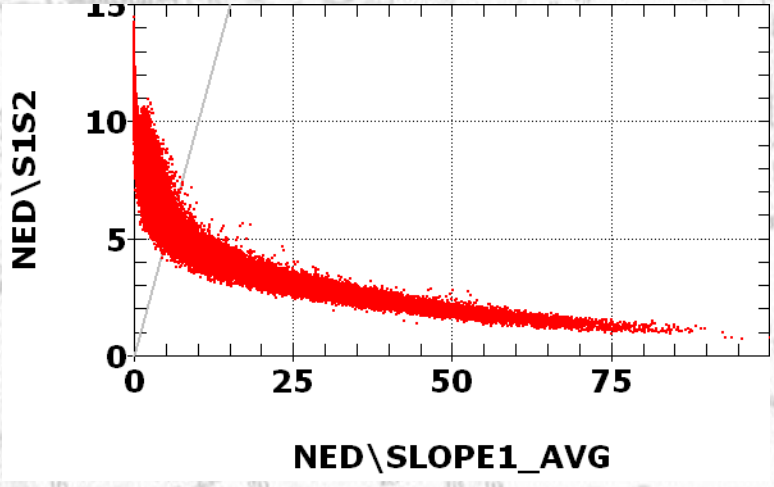
Slope Variables, NED

Field correlations n=497762

	ELEV_STD	PLANC_STD	PROFC_STD	ROUGH_FAC	SLOPE1_AVG	SLOPE4_AVG	SLOPE4_STD
ELEV_STD	1.0000	0.8090		0.8675	0.9018	0.8939	0.8200
PLANC_STD	0.8090	1.0000		0.9240	0.8717	0.8503	
PROFC_STD			1.0000		0.8348	0.8461	0.8825
RELIEF	0.8482						
ROUGH_FAC	0.8675	0.9240		1.0000	0.9676	0.9563	0.8020
SLOPE1_AVG	0.9018	0.8717	0.8348	0.9676	1.0000	0.9967	0.8770
SLOPE4_AVG	0.8939	0.8503	0.8461	0.9563	0.9967	1.0000	0.8833
SLOPE4_STD	0.8200		0.8825	0.8020	0.8770	0.8833	1.0000

ln(s1/S2) is also a slope measure, but non-linear because of logs





SRTM1 to NED Parameter Comparison

PARAMETER	CORRELATION R	SLOPE
ELEV_AVG	1.0000	0.9999
ELEV_STD	0.9944	0.9804
RELIEF	0.9973	0.9709
MAX_SLOPE	0.9104	0.8885
SLOPE1_AVG	0.9840	0.8350
SLOPE1_STD	0.9638	0.7977
SLOPE4_AVG	0.9863	0.8445
SLOPE4_STD	0.9718	0.8250
PLANC_STD	0.9361	0.6240
ROUGH_FAC	0.9869	0.8303
GAMMA_NS	0.9498	0.7246
GAMMA_EW	0.9342	0.6960
GAMMA_NESW	0.9519	0.7349
GAMMA_NWSE	0.9537	0.7348

PARAMETER	CORRELATION R	SLOPE
PROFC_AVG	0.8264	0.6156
PROFC_STD	0.8211	0.5052
FABRIC_DIR	0.8130	0.8006
QUEEN_ASP	0.8058	0.4358
STRENGTH	0.7881	0.4606
S1S2	0.8157	0.5239
ELEV_RELF	0.7167	0.5532

Correlation R: How well one series predicts the other

Slope: how well the values compare (if slope = 1, DEMs give the same value)

SRTM1 to NED Parameter Comparison

PARAMETER	CORRELATION R	SLOPE
SLOPE4_SKW	0.6681	0.4146
ELEV_SKW	0.6558	0.4659
S2S3	0.6324	0.4956
SLOPE1_SKW	0.6191	0.4017
GHOST_RAT	0.5314	0.4343
PROFC_SKW	0.4513	0.1040

PARAMETER	CORRELATION R	SLOPE
SLOPE1_CRT	0.3829	0.2575
SLOPE4_CRT	0.3815	0.1728
ELEV_CRT	0.3642	0.2091
SHAPE	0.2142	0.3200
PLANC_AVG	0.2160	0.0369
PLANC_SKW	0.1349	0.2217
PLANC_CRT	0.1196	0.1857
PROFC_CRT	0.0881	0.0087

Table 5. Selected Correlations above 0.90

PARAMETER	For 8 DEM Series	For 7 DEM Series	For 6 DEM Series
ELEV_STD	RELIEF		
GAMMA_EW	GAMMA_NESW GAMMA_NWSE ROUGH_FAC SLOPE1_AVG SLOPE4_AVG	PLANC_STD	GAMMA_NS
MAX_SLOPE		SLOPE1_STD	
PLANC_STD		GAMMA_EW GAMMA_NESW GAMMA_NS GAMMA_NWSE ROUGH_FAC	
RELIEF	ELEV_STD		SLOPE1_AVG SLOPE4_AVG
S1S2	STRENGTH		
SLOPE1_AVG	GAMMA_EW GAMMA_NESW GAMMA_NS GAMMA_NWSE ROUGH_FAC SLOPE4_AVG		RELIEF

Complete table in proceedings paper.

Table 6. Suggested variables for a terrain fingerprint.

Parameter	Descriptive Name	Notes
SLOPE_AVG	Steepness or Roughness	Evans, 1998. Pike (2001) listed 15 alternative measures. Pike (2001) most important variable.
ELEV_RELF	Elevation-relief ratio or Coefficient of dissection	Pike and Wilson, 1971. Pike (2001) third most important variable, linked to ELEV_SKW.
S2S3	Organization	Guth, 2003.
SLOPE_STD	Heterogeneity	Evans, 1998.
PROFC_STD	Curvature in profile	Evans, 1998.
PLANC_STD	Curvature in plan	Evans, 1998.
ELEV_AVG	Average elevation	Largely descriptive only. Evans, 1998. Pike (2001) second most important variable
FABRIC_DIR	Fabric direction	Largely descriptive only. Guth, 2003.
ELEV_KRT	Homogeneity	Evans, 1998. May be too noisy. Pike (2001) fourth most important variable, linked to ELEV_SKW.
ELEV_SKW	Massiveness (inverse)	Evans, 1998. May be too noisy. Pike (2001) third most important variable, linked to ELEV_RELF.
SLOPE_KRT	Modality	Evans, 1998. May be too noisy
SLOPE_SKW	Limitation	Evans, 1998. May be too noisy

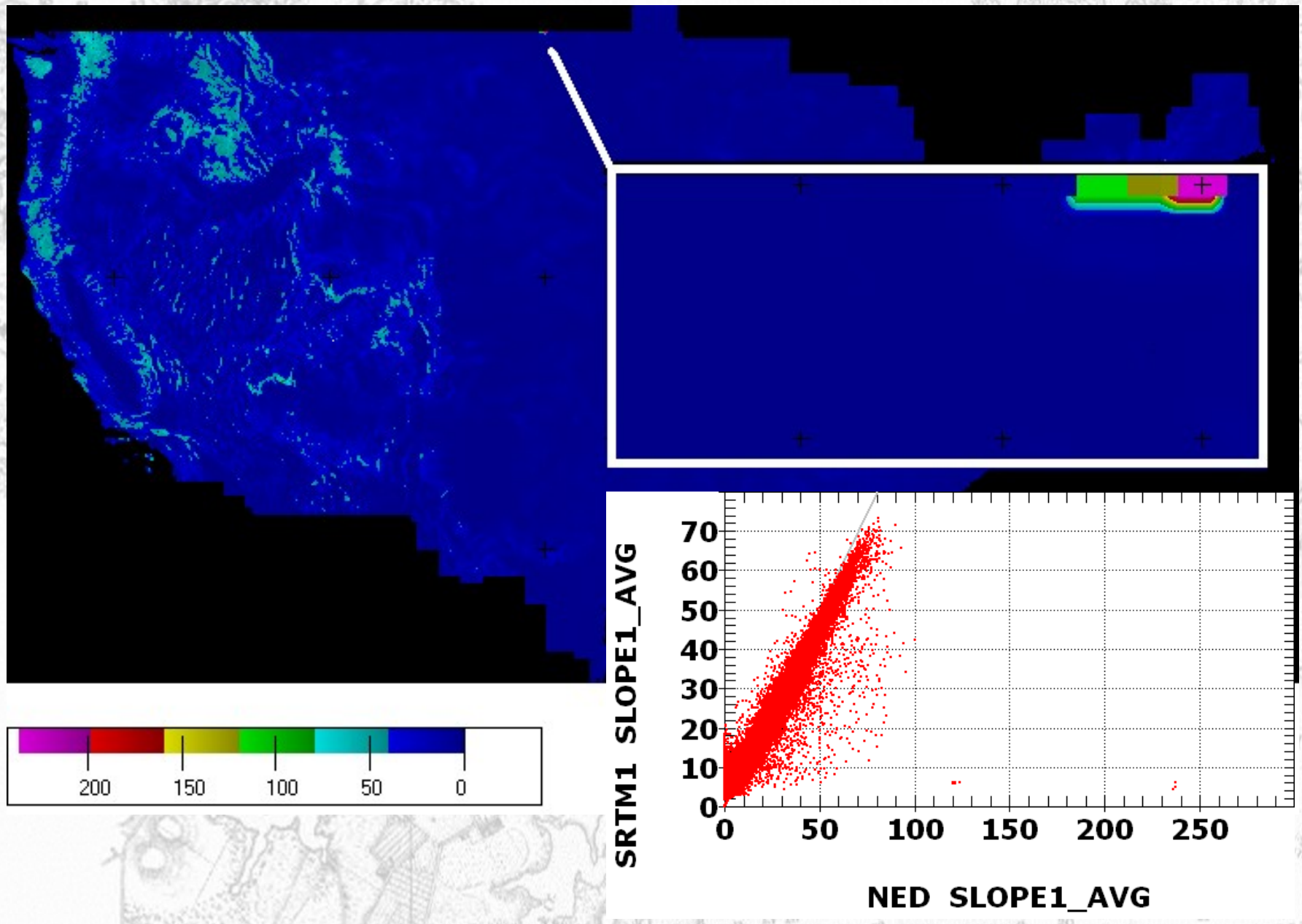
Results

- **Higher derivatives (e.g. curvature) are not robust, and change dramatically from one series of DEM to the next.**
- **Higher moments (skewness, kurtosis) have more noise and are less robust**
- **Only robust curvature measure is the standard deviation of plan curvature**
- **Most robust parameters are measures of elevation or slope**
- **Organization parameters, which depend on slope and aspect, are moderately robust**
- **A variety of geomorphic parameters really measure slope**

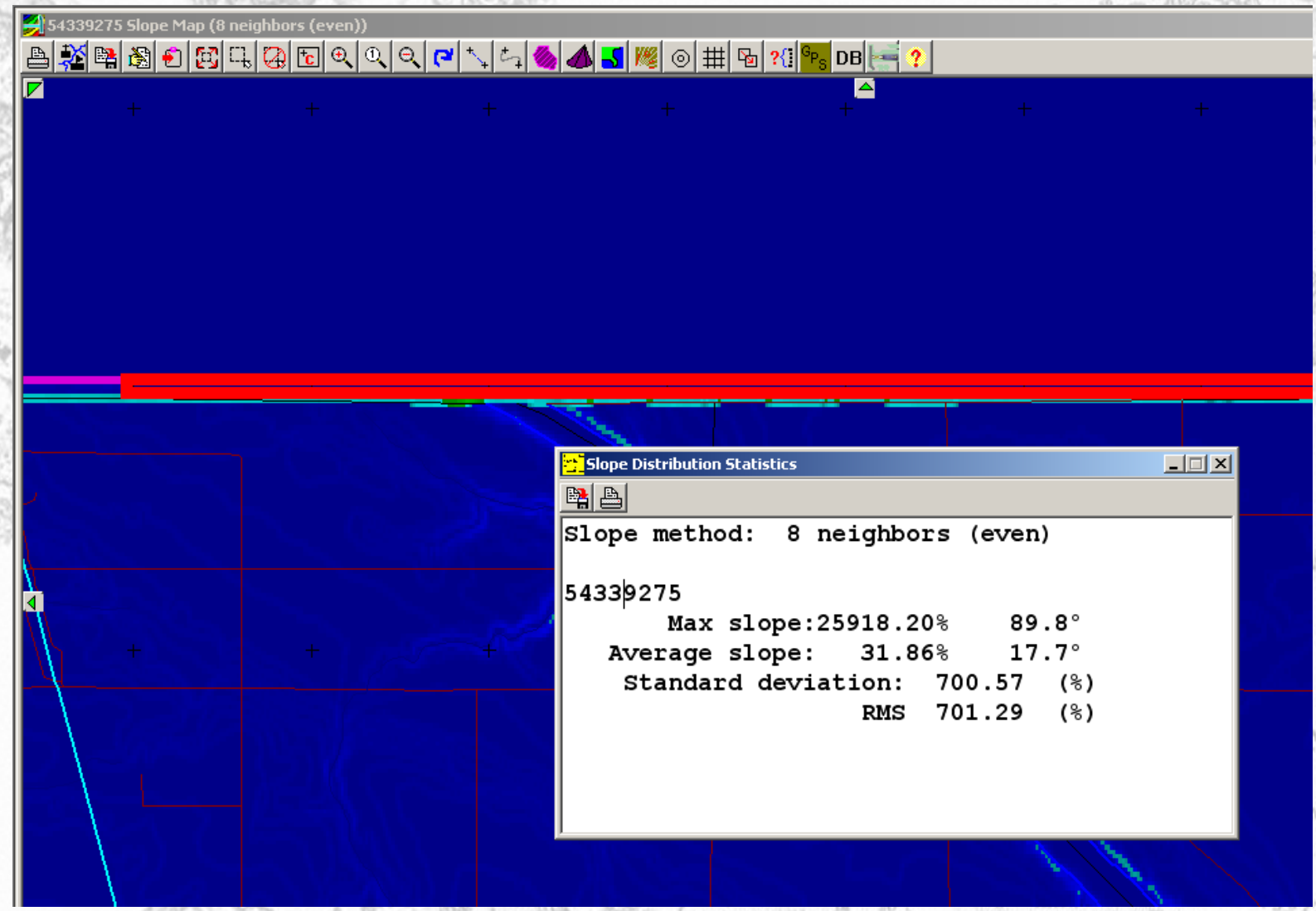
Geomorphic Conclusions

- DEMs at 10-100 m spacing capture a range of geomorphic parameters
- SRTM-3 is coming worldwide; need to know what geomorphometry it captures and what it degrades
- Need to extend analysis for IFSAR (~5 m, 500 GB for US) and LIDAR (~1 m, 12.5 TB for US) data

NED Average Slopes

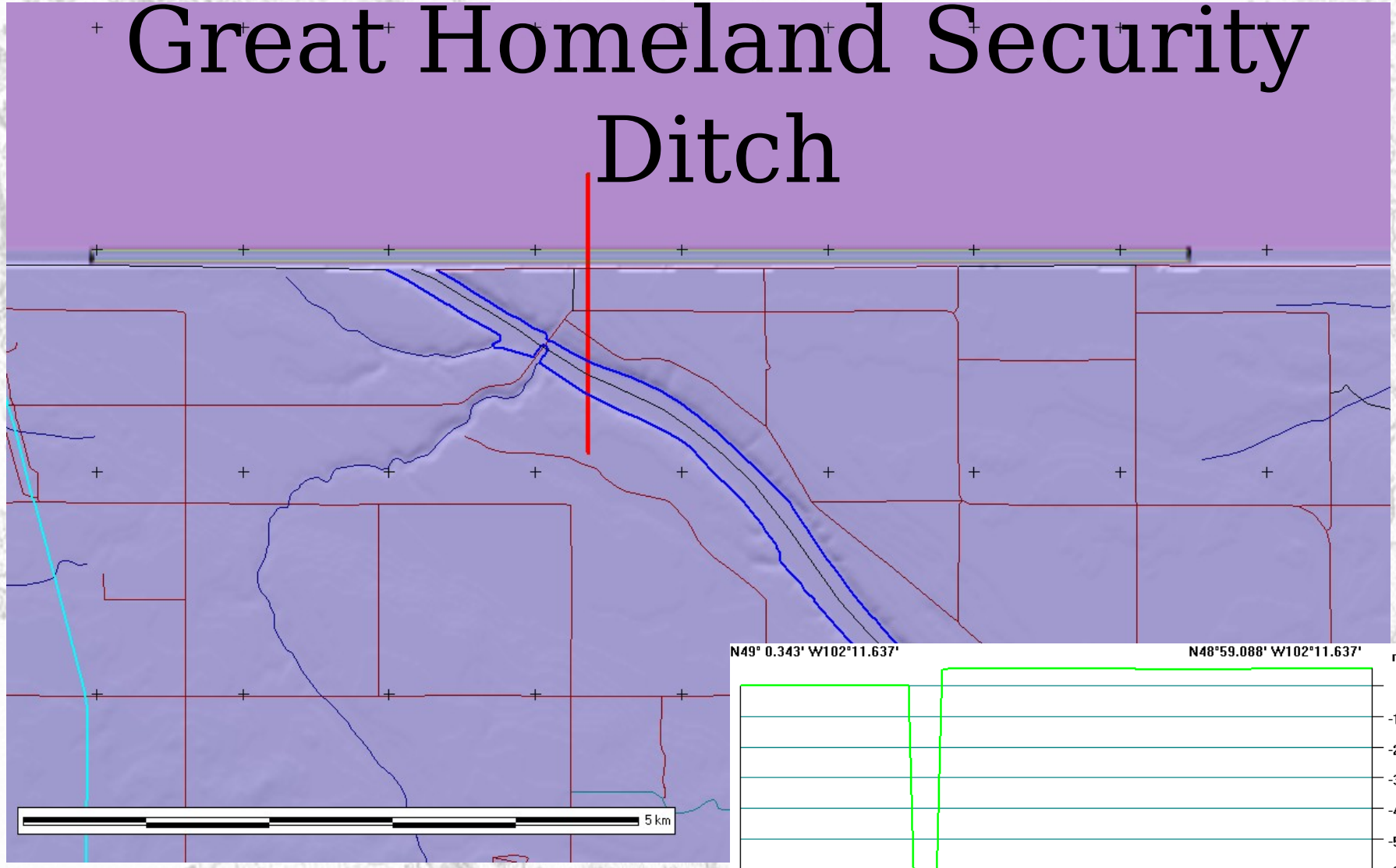


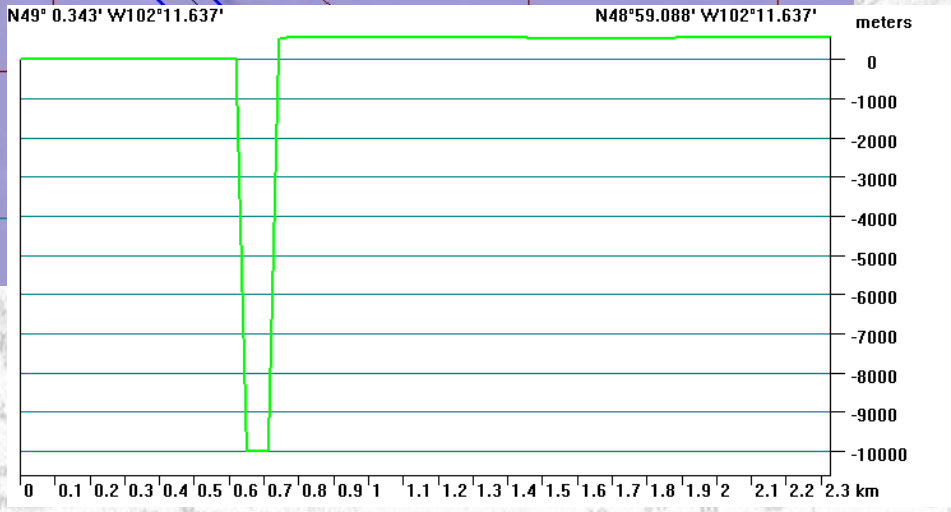
Slopes Near the Ditch



Red pattern highlights slopes over

Great Homeland Security Ditch





NED along the Canadian Border, W102

- **Canada set to 0**
- **Missing data along border set to -9998 and -10000 rather**

DEM TERRAIN FINGERPRINTS

- **Capture terrain characteristics, across a range of scales and collection methods**
- **Should be used in quality control & hole filling**
- ***If a DEM doesn't accurately portray the landscape, how accurately does it really meet your needs?***

MicroDEM UAV Development Work—A Progress Report

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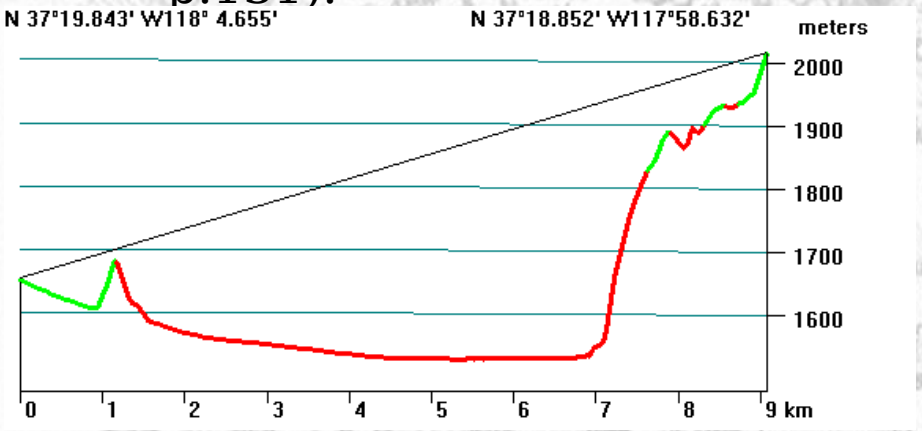
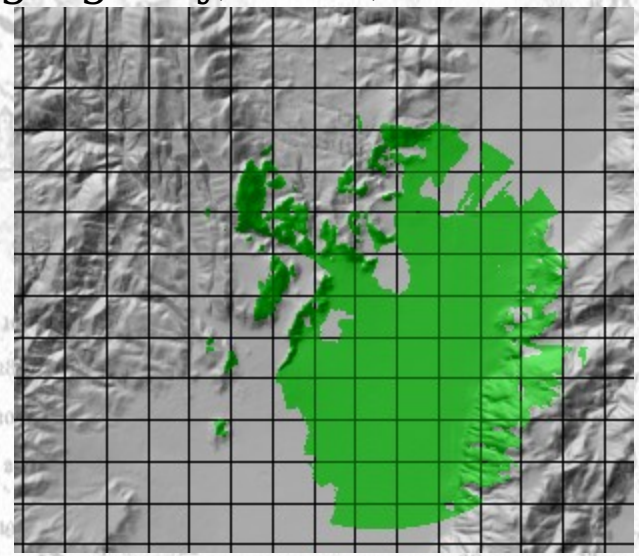
July 20, 2004

Intervisibility: "function which calculates area or line-of-sight which can be 'seen' from a specific location or locations"

(Defense Mapping Agency, 1994, p.131).





Intervisibility Depends On:

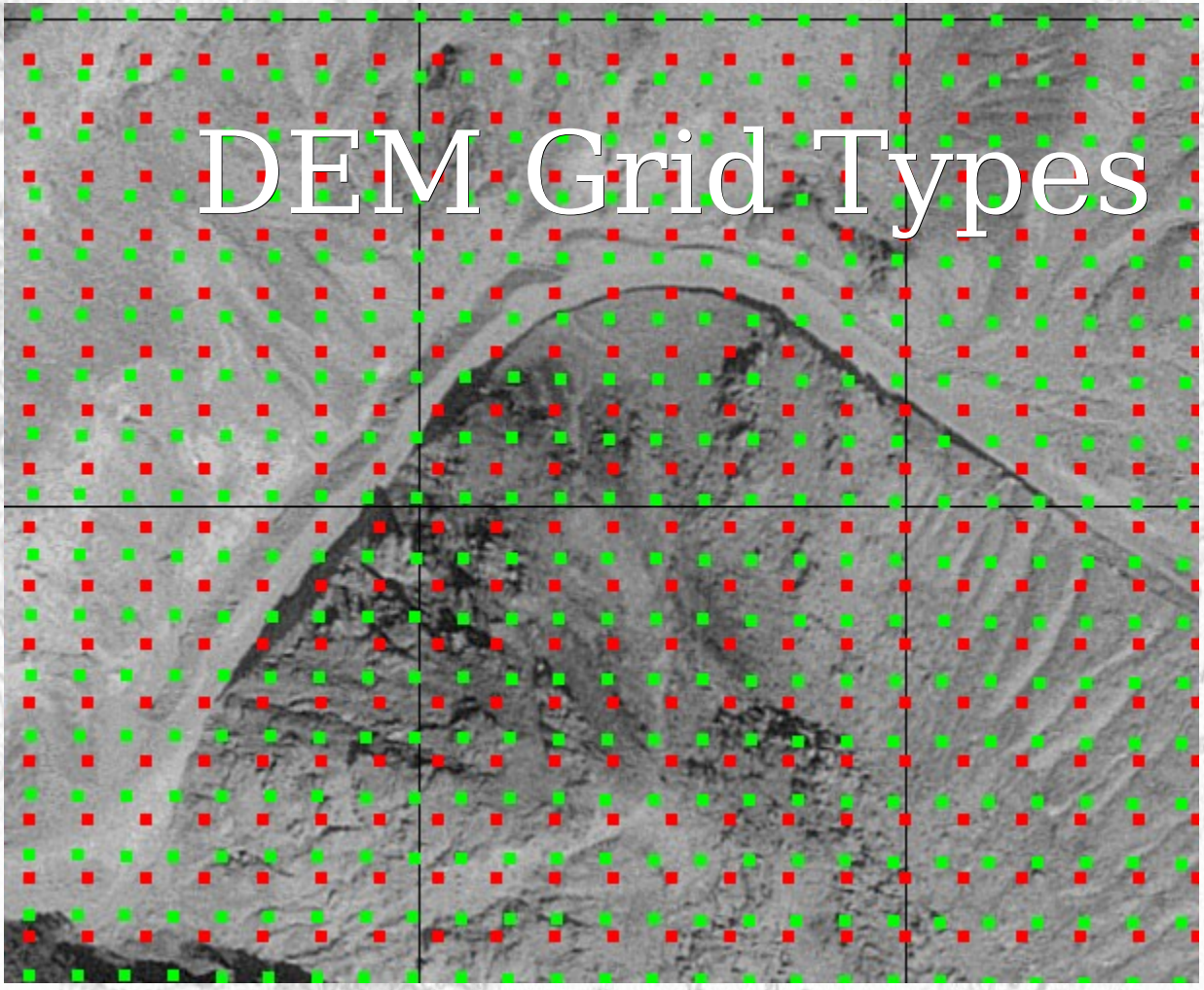
- DEM characteristics
- DEM accuracy and errors
- Vegetation and buildings
- Atmospheric effects
- **Geometric model**

High resolution, readily available DEMs for intervisibility.

DEM	Producer	Data Spacing	Coordinates
NED	USGS	1” or 1/3”	Geographic
Native	USGS	30 m or 10 m	UTM
DTED	NIMA	3” or 1”	Geographic
SRTM	NIMA-NASA	3” or 1”	Geographic
ASTER	NASA	30 m	UTM

Hi-res LIDAR, IFSAR DEMs might have different challenges

DEM Grid Types



1 m DOQQ

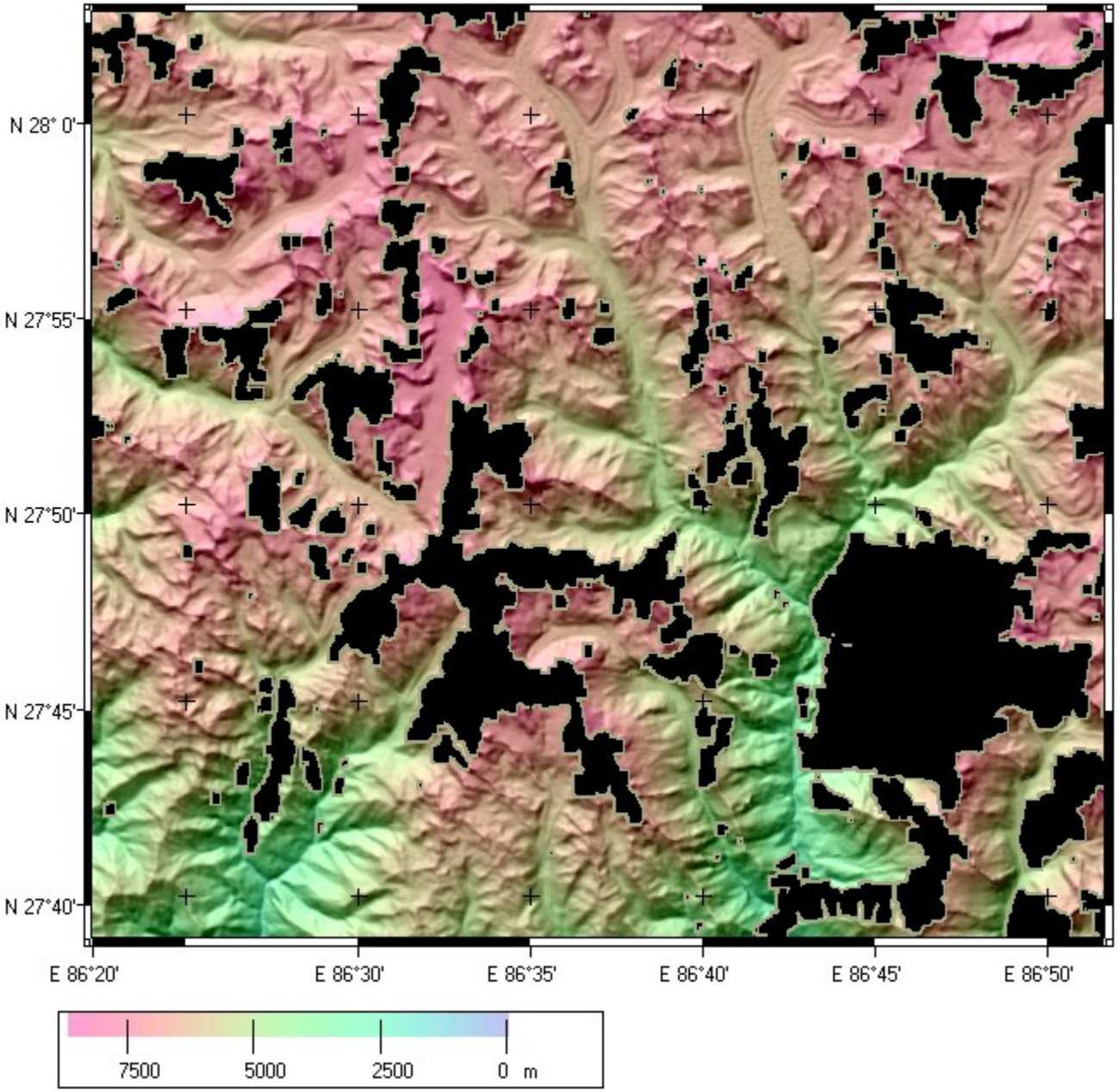
30 m USGS SDTS DEM—square grid

1” USGS NED DEM—almost rectangular seamless grid

For the foreseeable future, military units will have DEMs:

- Geographic spacing (DTED and SRTM)
- Relatively large data spacing, 1” or 3”
- SRTM 1” data inferior to USGS products, so effective resolution is worse than 1” (but outside US, better than alternatives)

Swiss Cheese SRTM DEM in Himalayas



Line-of-Sight (LOS) Compendium

Prepared for the

Line-of-Sight Technical Working Group (LOS TWG)

Sponsored by

U.S. Army Corps of Engineers
Engineer Research and Development Center/ Topographic Engineering Center (ERDC/TEC)

Working Document
April 18, 2004

Version 0.1

Algorithm	DEMs	Features	Sensor/Target Height	Vertical Curvature	Point Interpolation	
DYNTACS (Yoeli)	UTM grid	Vegetation/urban	User defined	Flat earth, curved earth, radar	Four point linear	
Bresenham	UTM grid	Vegetation/urban	User defined	Flat earth	SW corner	
BTRA	UTM grid	Opaque features	User defined	Flat earth, curved earth, radar		
PVNT	UTM block data structure	Vegetation	User defined	Flat earth		Point to area
JWARS	UTM grid	Bare earth only	Constant target height Variable sensor height	Flat earth	Bilinear interpolation	Point to point
PLOS	UTM grid	Bare earth only	User defined	Flat earth	Four point linear	
MICRODEM	UTM grid or lat/long grid	Bare earth only	User defined	Flat earth, curved earth, radar	Bilinear interpolation	Point to point
GRASS	"Standard" grids		Target on ground	Flat earth		
JANUS						
ModSAT	TINs					
ZCAP	Proprietary database					
ARENA--spacing along radials	DTED	Bare earth only	User defined	Flat earth, curved earth, radar		
SEEFAR	DTED	Bare earth only	User defined sensor	Flat earth, curved earth, radar		Point to area

Guth table from LOS-TWG compendium

Problems with UTM-only Algorithms

- Military has lat/long DTED and SRTM
- Reprojection changes the DEM (horizontally and vertically)
- Changes “worst” at the ridge tops, which control LOS
- Problems at UTM zone boundaries
- Problems with very long profiles
- Reason both NGA and USGS went seamless

Intervisiblity Algorithm Geometric Options

Selection	Choices
Viewer and target locations	Nearest grid postings, Interpolated
Interpretation of viewshed	Point-to-Point, Point-to-Cell, Cell-to-Cell, or Cell-to-Point
Point interpolation	Nearest point, Point to SW, average nearest points, Weighting to nearest points, Bilinear interpolation, Triangle interpolation, Polynomial interpolation, Splines
Point selection along radials	Nearest grid postings, Grid square sides, Grid triangle sides, Spacing along radial
Creation of viewshed	Spaced radials, point to point for every grid posting
Vertical earth curvature	None, Earth shape, Earth shape plus refraction
Horizontal earth curvature	DEM grid, UTM, simple geographic, geodetic

Intervisiblity Algorithm Geometric Options

Selection	Justification
Viewer and target locations, Interpolated Interpretation of viewshed, Point-to-Point	DEM models a continuous surface , and we need specific locations. We have moderate resolution DEMs with grid postings that are not sufficiently accurate.
Point interpolation, Bilinear interpolation	Reasonably smooth surface and reasonable execution times.
Point selection along radials, Spacing along radial	Spacing can be adjusted to capture peaks and ridges. With geographic grids, alternatives are not simple to compute because DEM grid does not provide straight path. With UTM DEM and short sight-lines, other options equally good.
Creation of viewshed, Spaced radials	Fast execution, guarantee to show either every masked or every visible point at any display scale, and ability to model sub-pixel regions.
Vertical earth curvature, Earth shape plus refraction	For visible light, use integrated correction from TM-551 or Yoeli (1985). Can ignore under 1 km, must consider over 5 km.
Horizontal earth curvature, geodetic	Works for both UTM and geographic DEMs, and across UTM zones. Could use UTM for short sight-lines in one UTM zone.

MICRODEM Summer 2004 Work

- Investigate permissible shortcuts
- Optimize LOS/viewshed algorithms
- Make viewshed thread safe for multi-processors
- Grid computing for viewshed
- Start putting modules into libraries to call from another language
- Add target overview option
- Compute percentage of fan/target area covered

MICRODEM Program

- 220,000 lines of Delphi (Object Pascal) source code
- Goes back 20 years to Turbo Pascal
- RAD, excellent database support
- Object oriented
- Uses Windows API in places (e.g. printing, clipboard)
- Could recompile for Linux or .NET with “some” effort
- Could place in libraries to use with other languages with “some effort”
- Currently single executable, about 4 MB

Intervisibility Algorithms Requirements

- Work with both UTM and lat/long DEMs
- Work at both short and long ranges

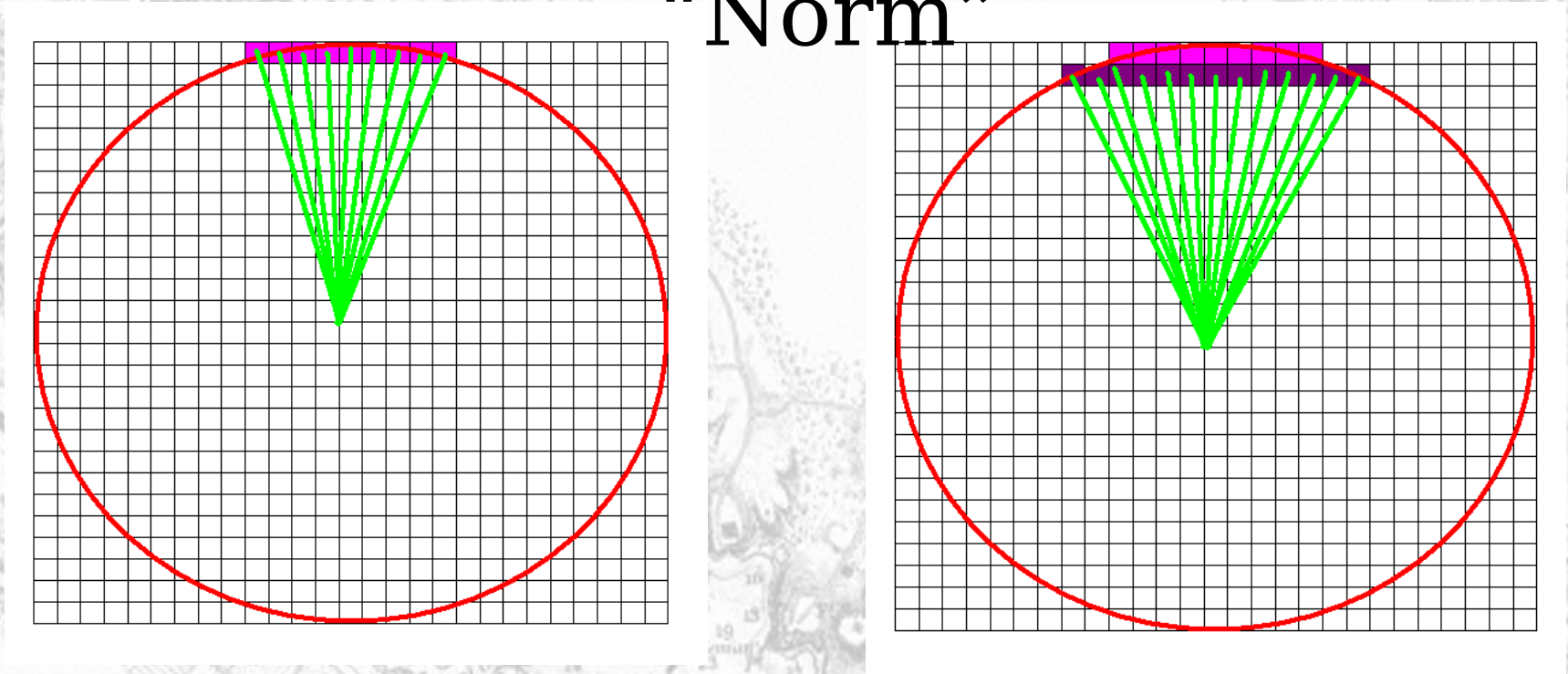
LOS Algorithm

- Get coordinates of “straight-line” points between end points, with desired spacing interval
- Get elevations of points, with refraction/curvature corrections
- Determine visibility of each point (compare vertical angles)
- Can bail out fast if only YES/NO intervisibility required (first ridge that blocks)
- Compute % of points visible

Viewshed Algorithm

- Get radial with LOS algorithm
- Project each point onto map
- Color masked/visible points
- Draw next radial
- Sum masked/visible to compute percent coverage

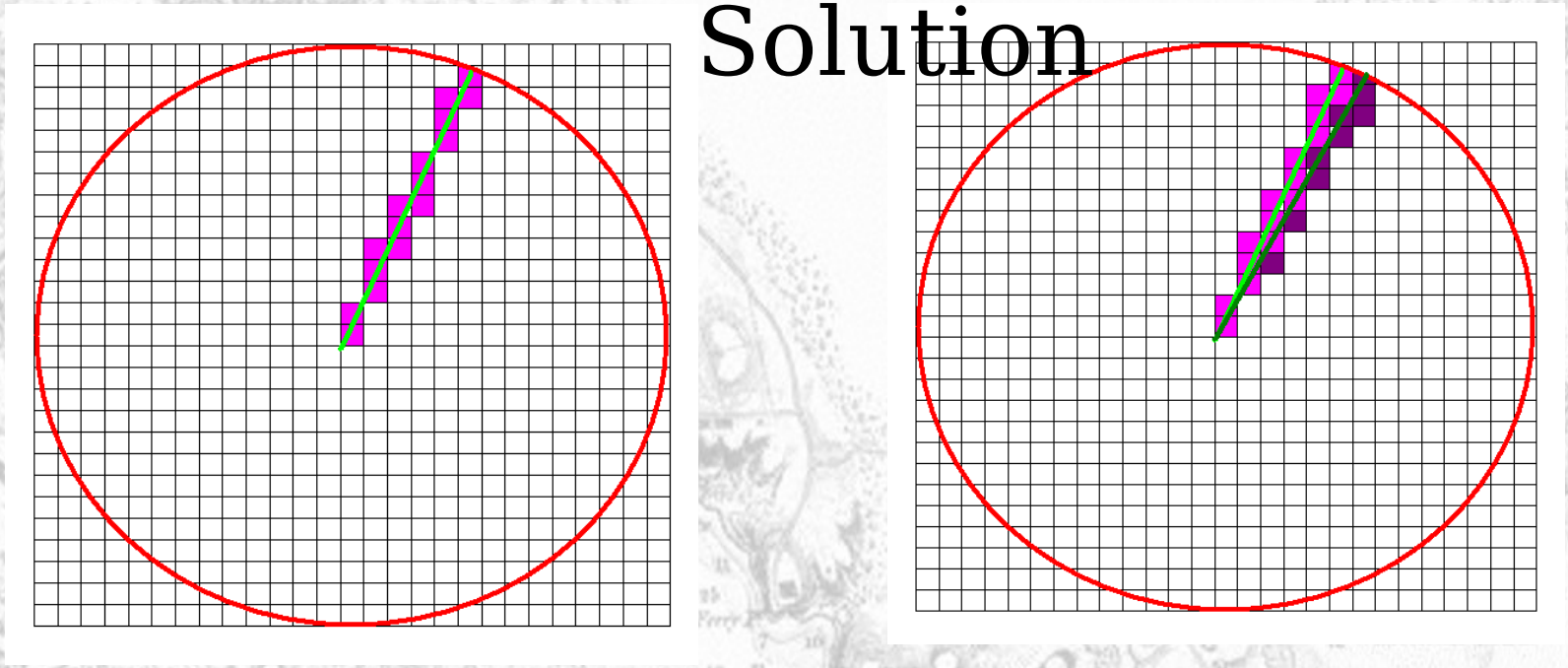
Point to Point Viewsheds—Current "Norm"



Boxes are DEM grid

1. From the viewer's location, run intervisibility to every grid point in the DEM.
2. Often Cell-to-Cell, for applications that want to precompute and save.
3. In general cannot use intermediate grid cell results since they do not lie on lines.

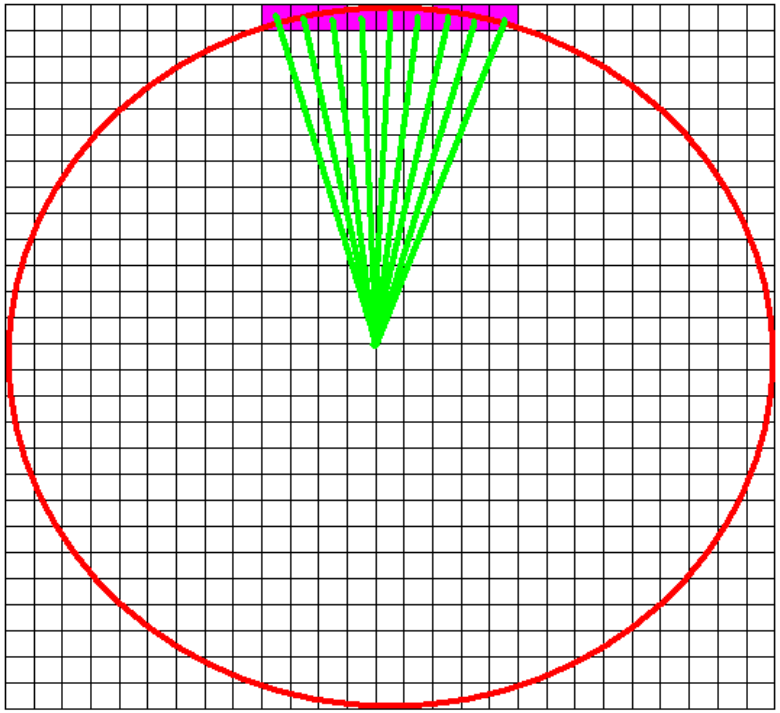
Spaced Radial Viewshed—Proposed Solution



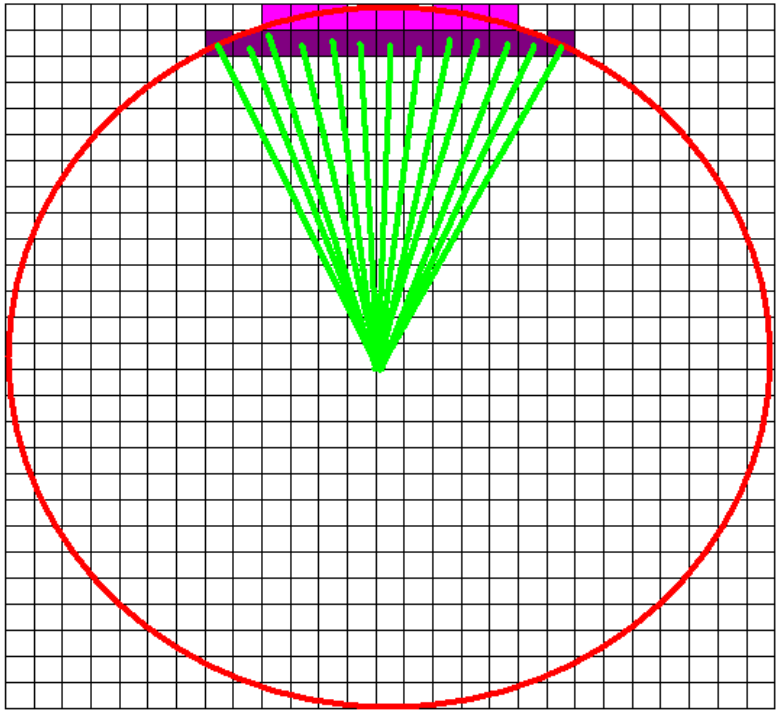
Boxes are display pixels

1. **From the viewer's location, run radials with angular separation so that they cover every pixel on fan perimeter.**
2. **Compute intervisibility along radial. Spacing for computations is pixel resolution, or half the DEM spacing, whichever is less. Intermediate points along radial determined as by-product of end point computation.**
3. **Select whether to show visible or masked points. Except at the very perimeter, multiple calculations will be done for each pixel, but only the selected state will be drawn.**
4. **To rescale the diagram, recompute. All visible (or masked areas) are**

Viewshed Comparision



Radials--86 computations



Point to point--597 computations

In the radial method, only points on the circumference are computed and all interior points are filled in as a byproduct. In the Point to point method, each point in computed separately. In this case the difference is a factor of 6. As the region size increases, the radial method increases with the radius, and the point to point method with ½ (radius)^2.

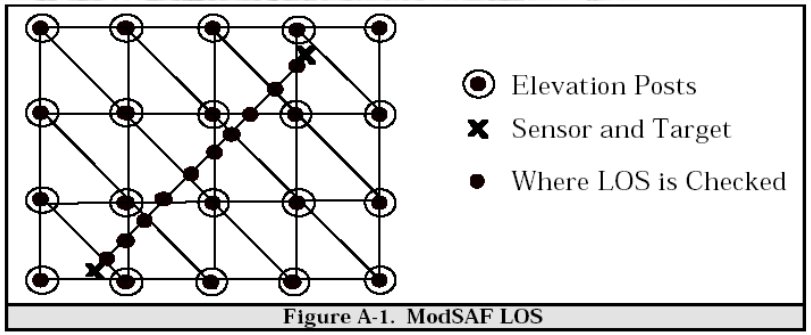


Figure A-1. ModSAF LOS

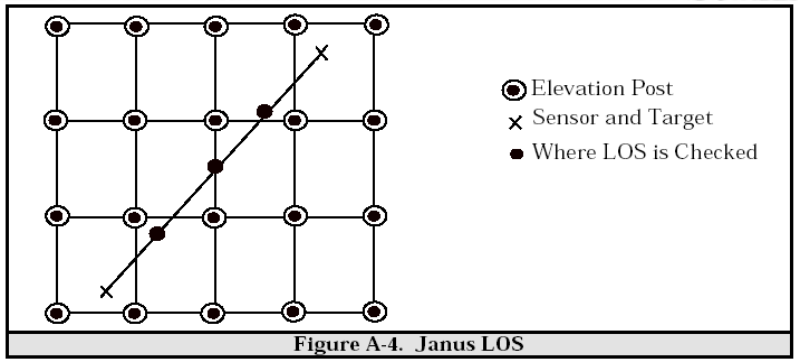


Figure A-4. Janus LOS

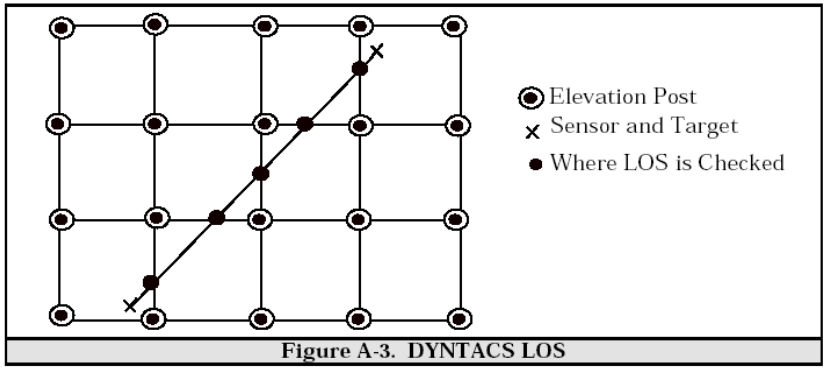


Figure A-3. DYNTACS LOS

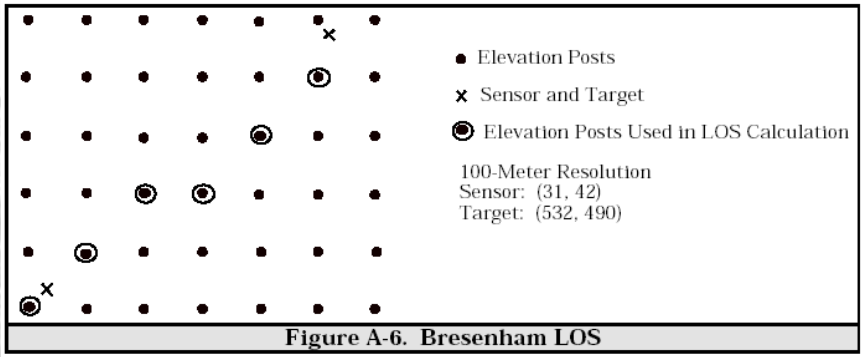


Figure A-6. Bresenham LOS

Point selection along intervisibility radial

Descriptive Name	**Military Model** Champion and others (1995)	**References**
Nearest Posting	Breshenham	
Grid Square Sides	DYNTACS	Yoeli, 1985
Grid Triangle Sides	ModSAF	
Radial Interpolation	JANUS	

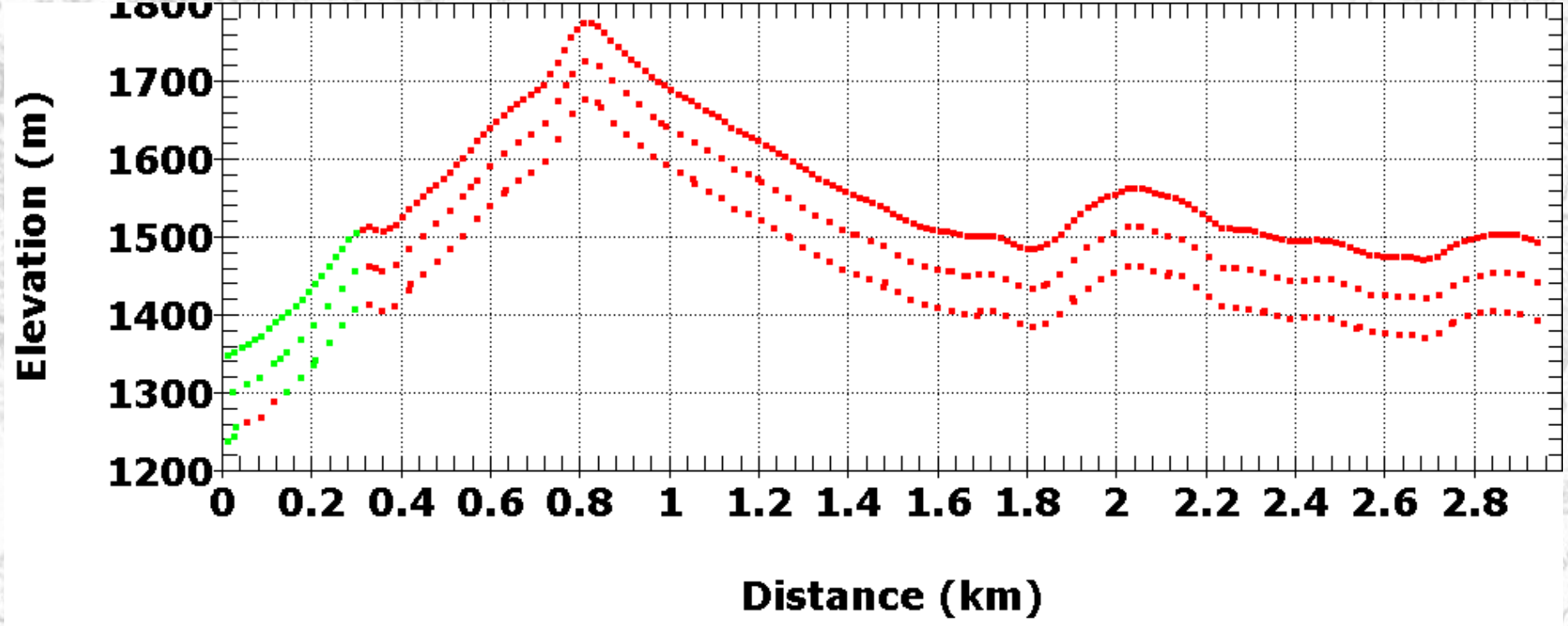
TRAC-WSMR-TR-95-032(R)

The Effects of Different Line-of-Sight Algorithms and Terrain Elevation Representations on Combat Simulations

TRAC WSMR

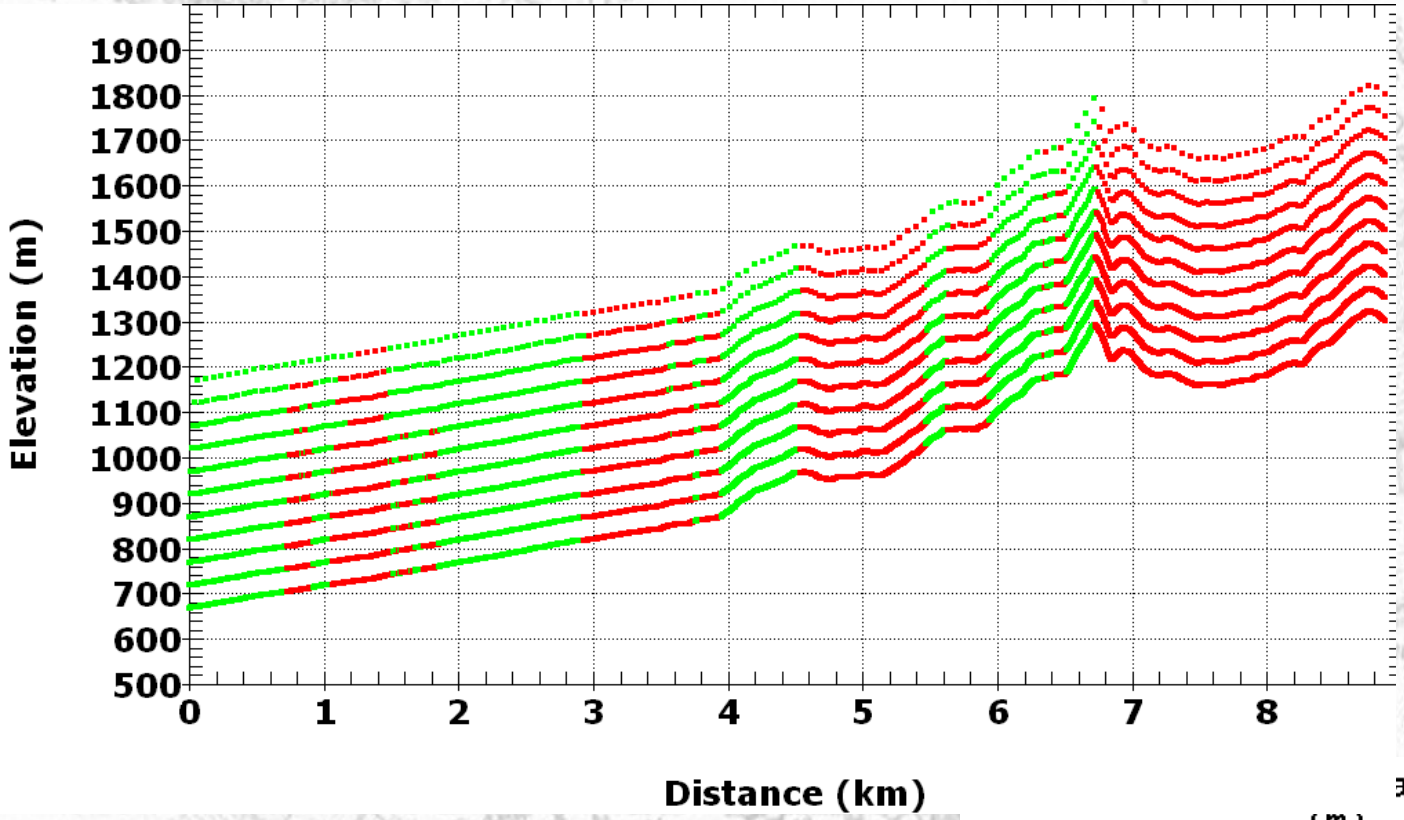
TEC

Figures from Champion et al., 1995



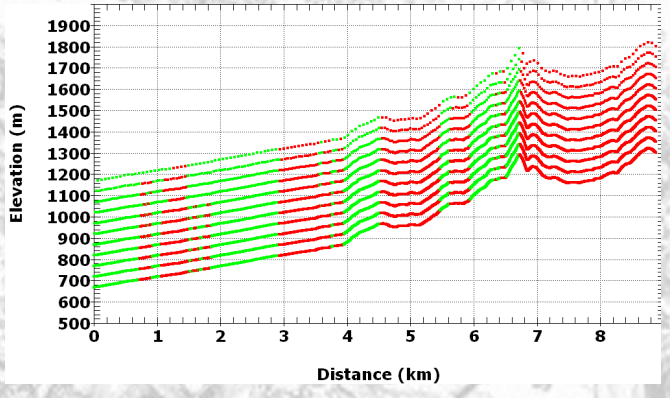
Point Selection Along the LOS

- Top--radial spacing.
- Middle--grid square sides. Note the variable spacing, with two points close together where the profile clips a corner in the data grid.
- Bottom--nearest grid neighbor (Bresenham). Note the occasional bumps and steps, where in steep terrain you get very different results depending on which side of the profile the nearest point occurs. Note that this is the only one of the algorithms to show masked terrain about 100 meters from the observer, because the third point out creates an artificial bench.



- **10 m DEM**
- **Effect of varying spacing along LOS**

	acing (m)	Coverage (%)
149	59.6	49.66
198	44.8	46.46
297	29.9	44.44
445	19.9	47.42
593	15.0	43.17
888	10.0	40.99
1776	5.0	41.78
2220	4.0	40.14
2959	3.0	40.42
4438	2.0	40.29
8876	1.0	40.20



Points	Point Spacing (m)	Coverage (%)
149	59.6	49.66
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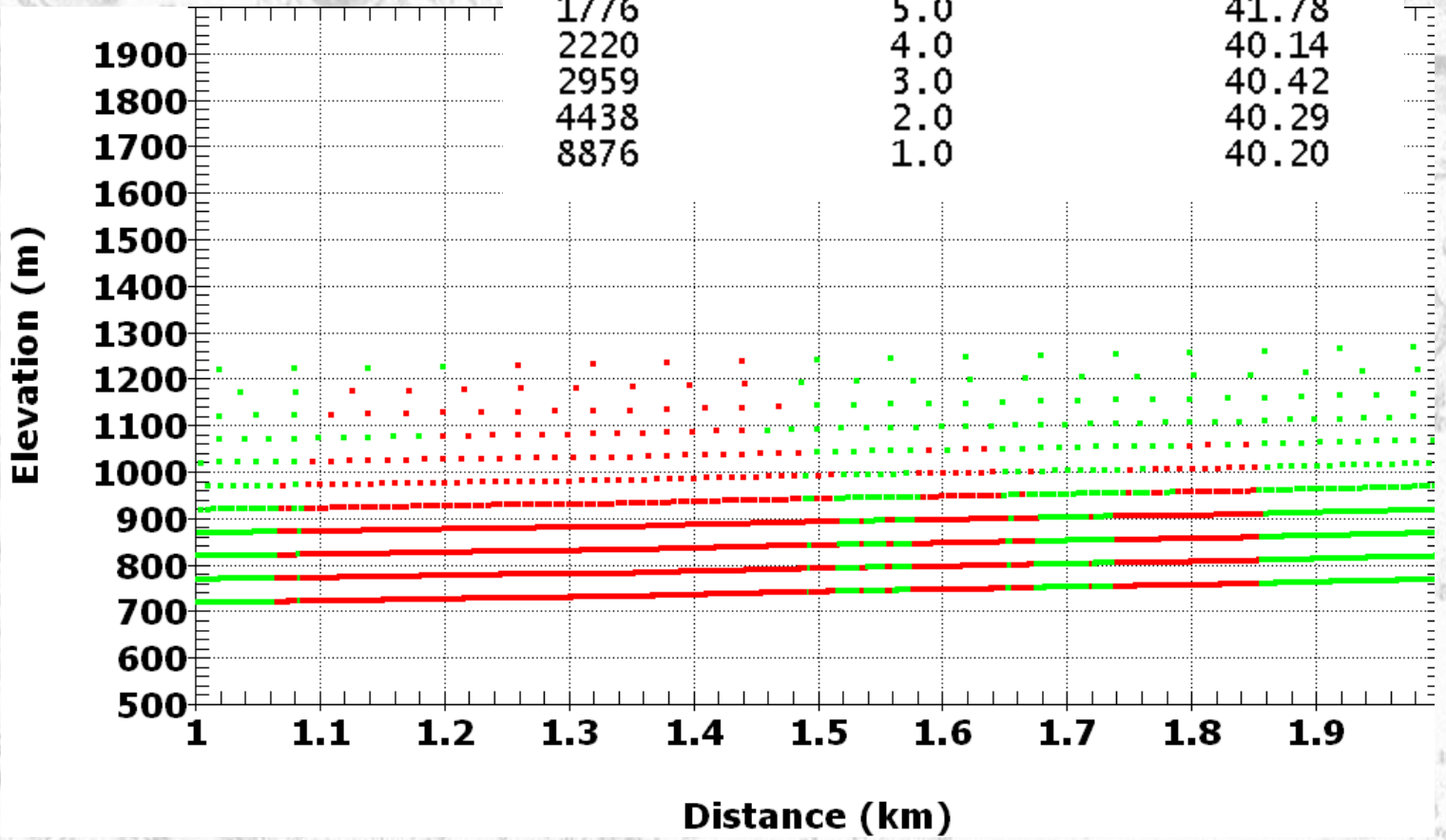
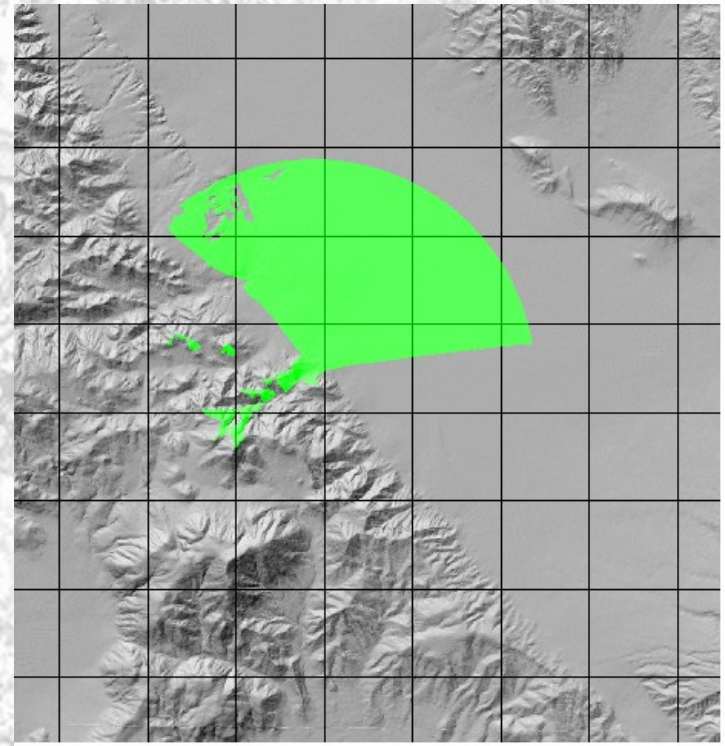
2959	3.0	40.42
4438	2.0	40.29
8876	1.0	40.20



Spacing along Radial

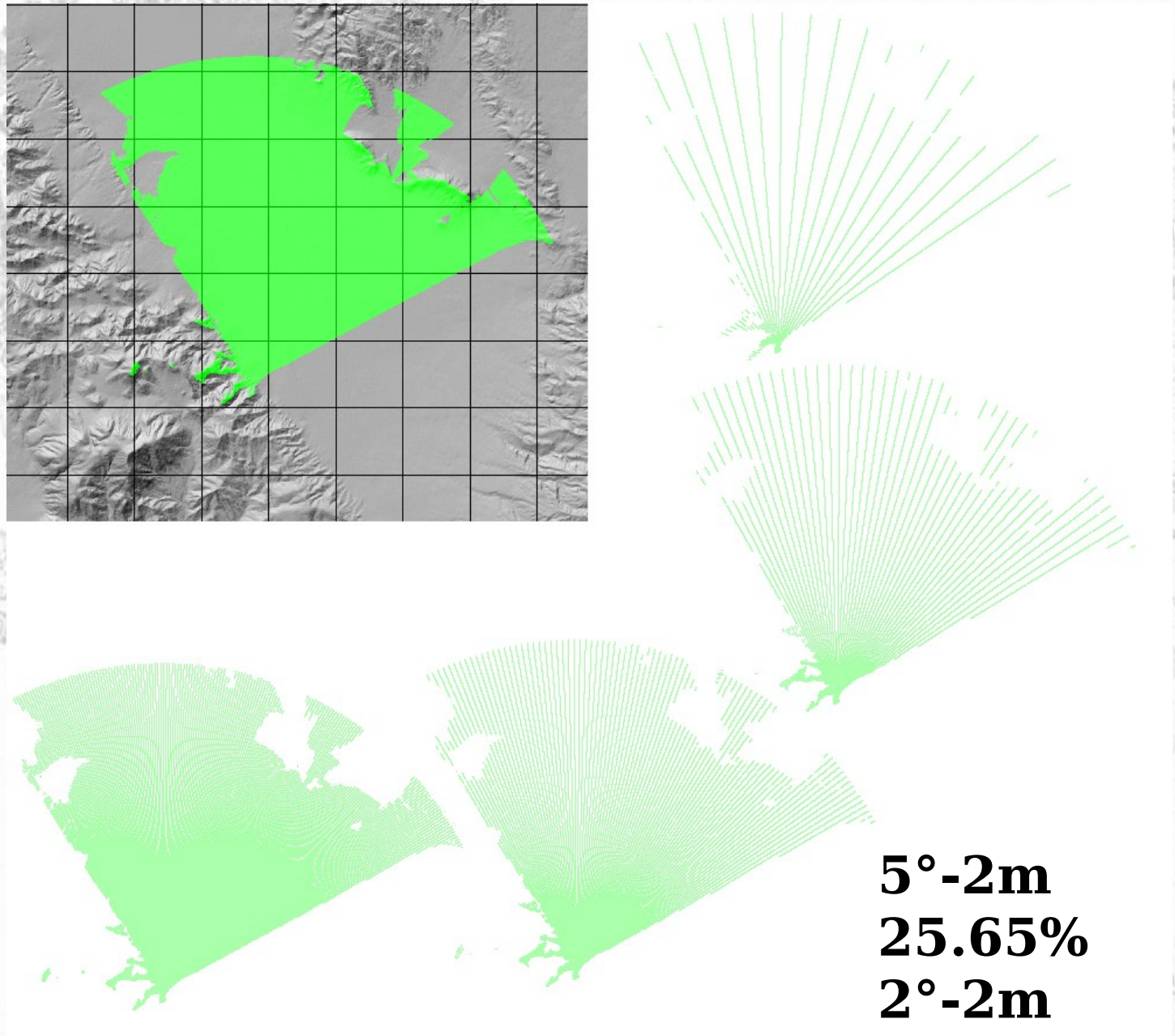
- Nyquist limit
- Suggest < ½ DEM Spacing adequately captures results



5 km Fan

10 m DEM

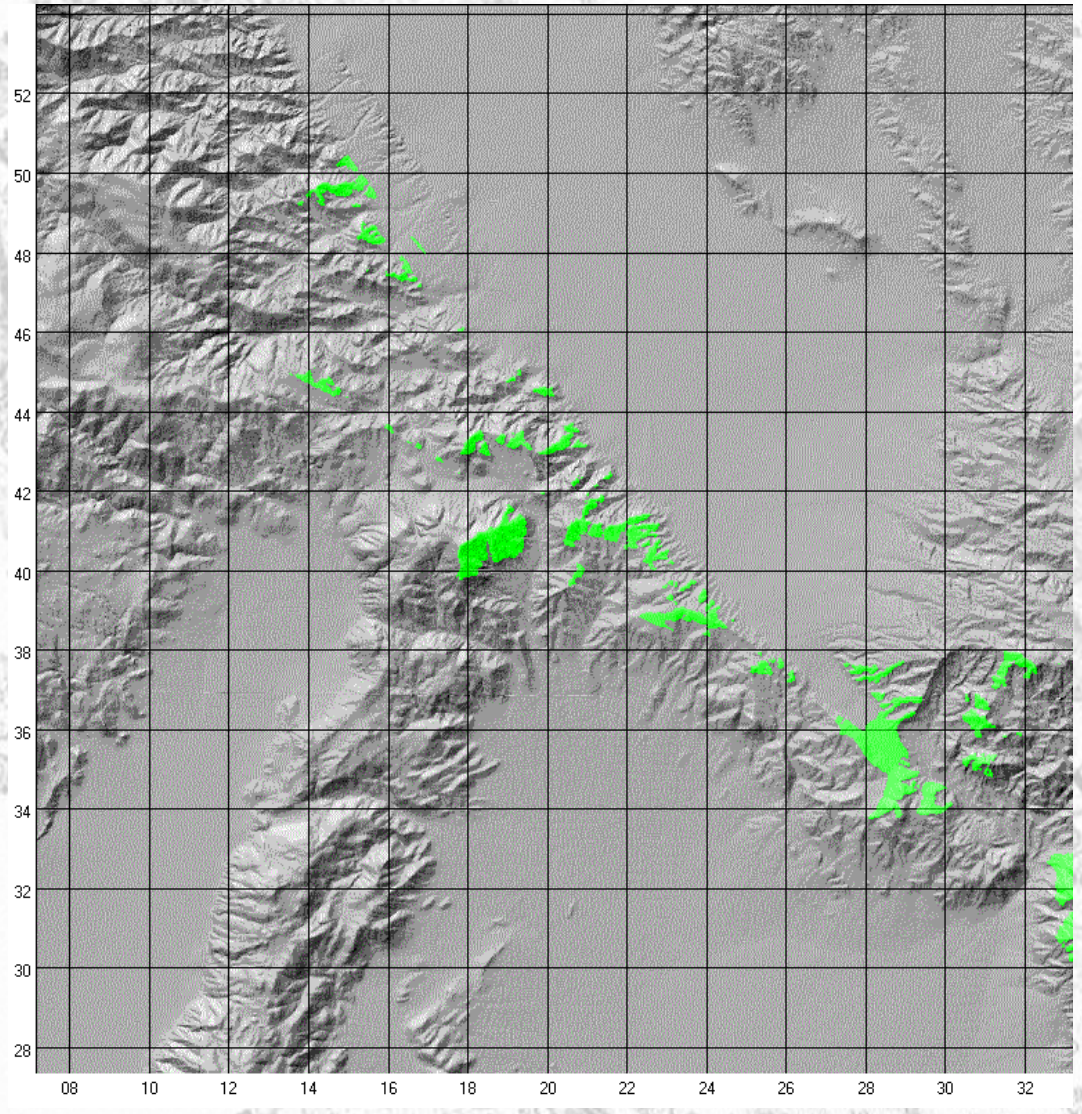
5°-5m	**0.14 sec**	**35.21%**
2°-2m	**0.47 sec**	**34.05%**
1°-2m	**0.88 sec**	**33.65%**
0.5°-2m	**1.70 sec**	**33.46%**



10 km fan

10 m DEM

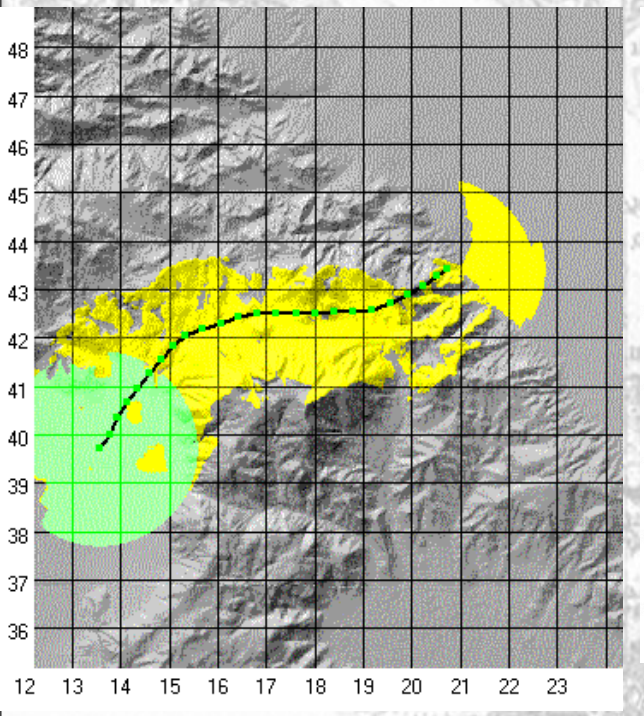
5°-2m	0.36 sec
25.65%	
2°-2m	0.83 sec
24.25%	
1°-2m	1.56 sec

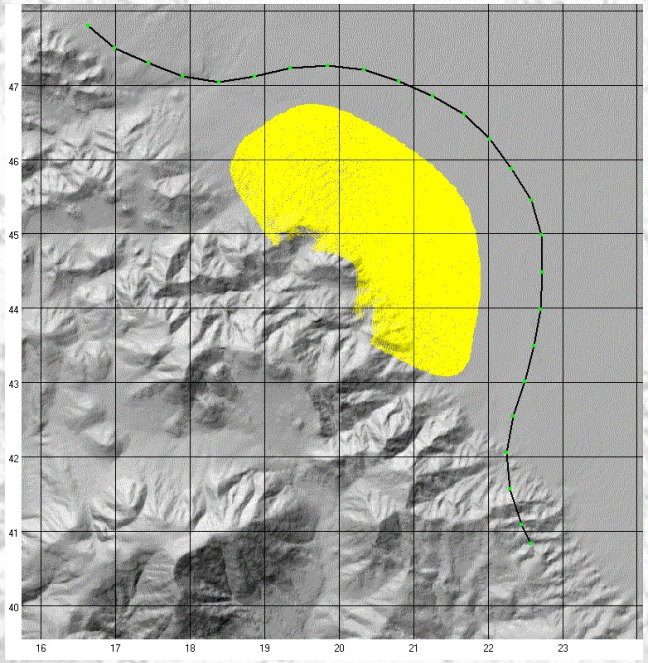


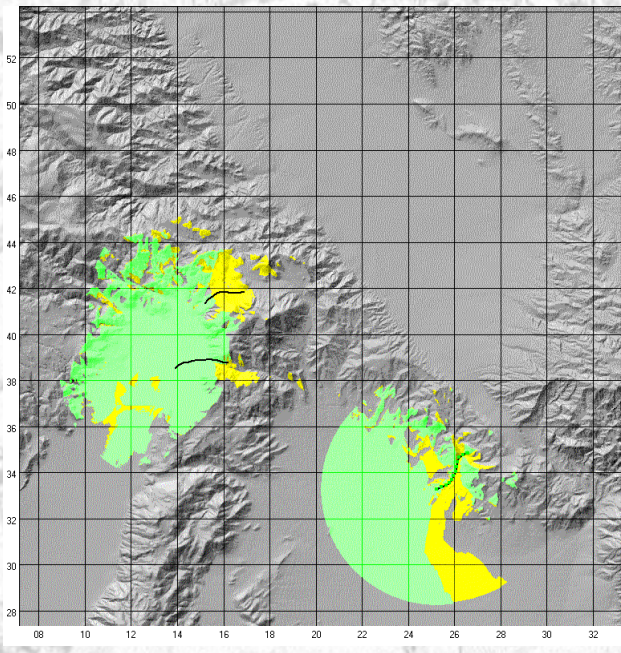
20 km Fan
10 m DEM

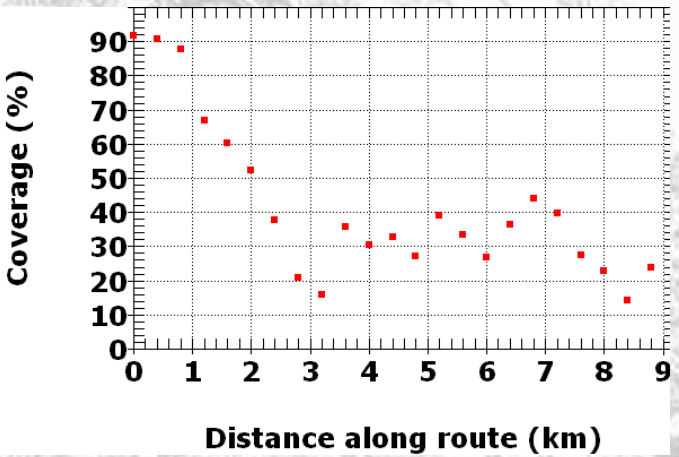
5°-2m	**0.27 sec**
7.35%	
2°-2m	**0.59 sec**
7.44%	
1°-2m	**1.13 sec**
7.43%	
0.5°-2m	**2.20 sec**
7.44%	

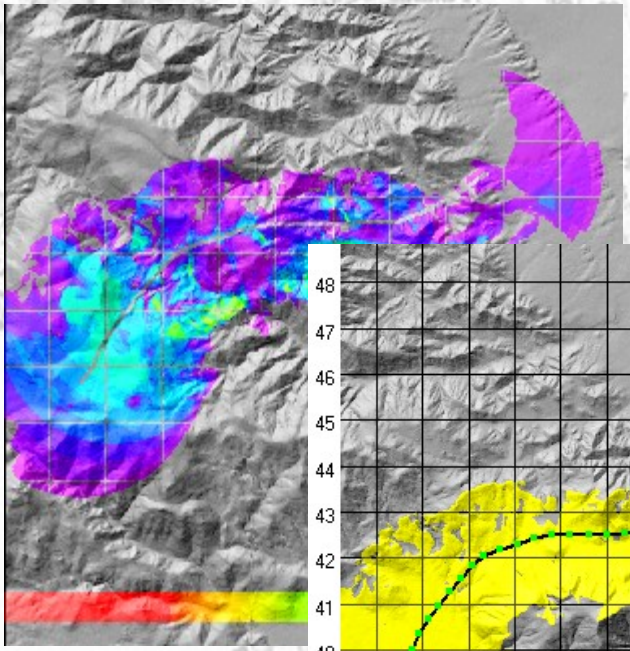
Animations/Movies

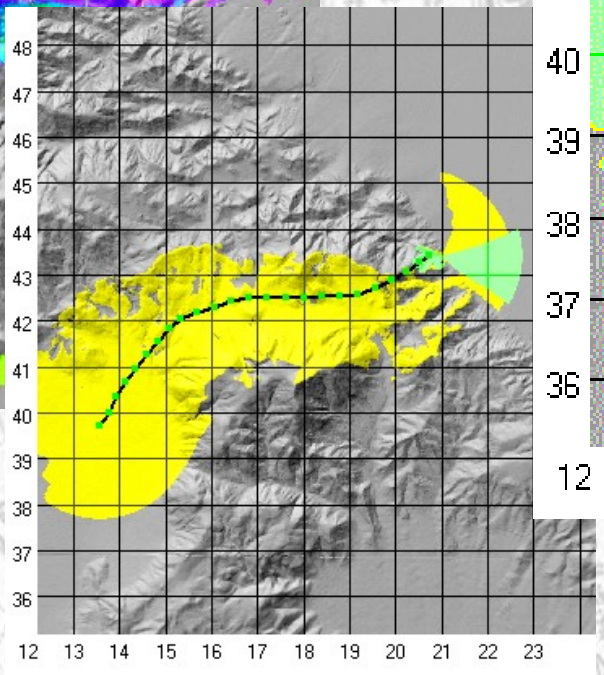


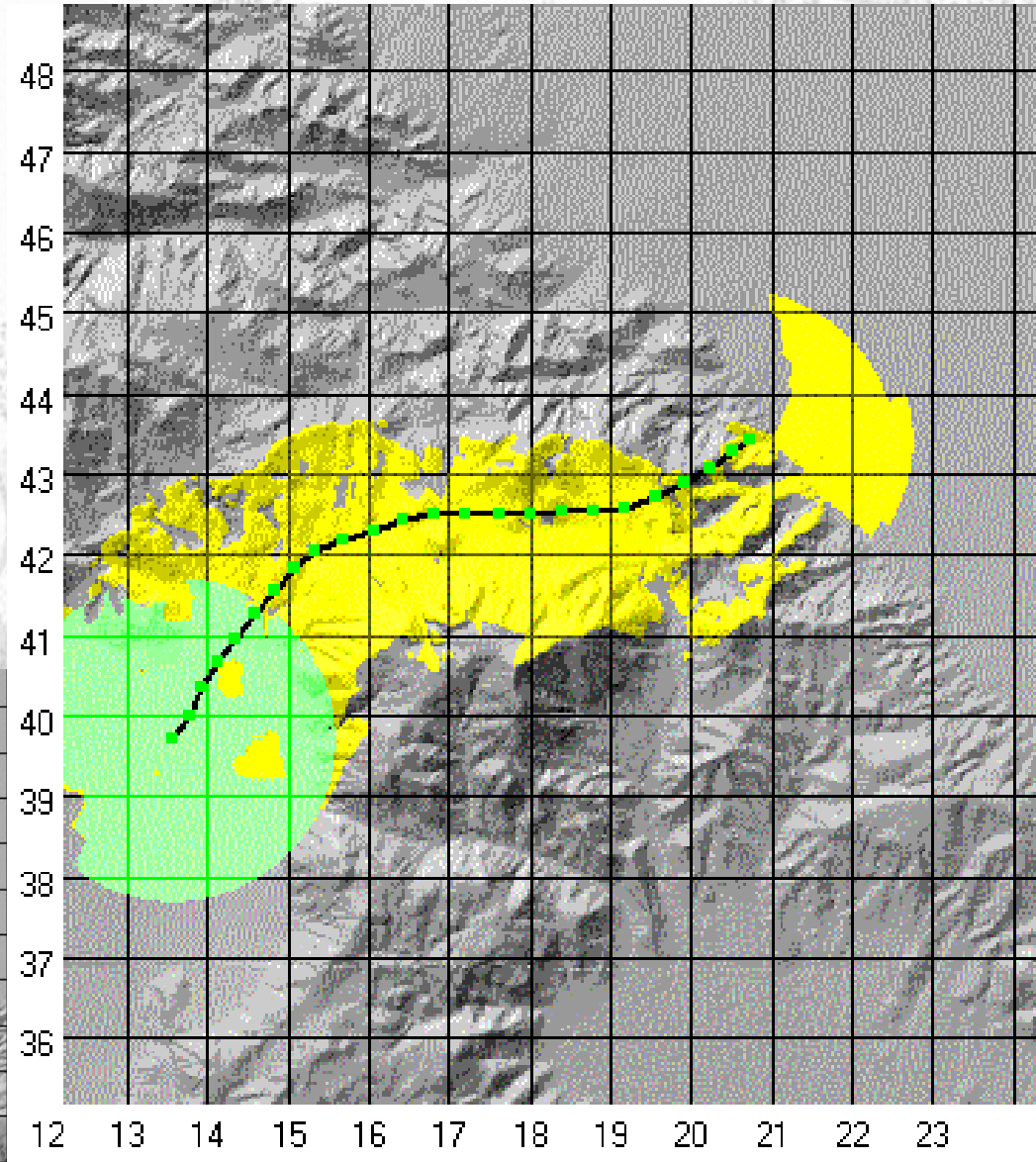




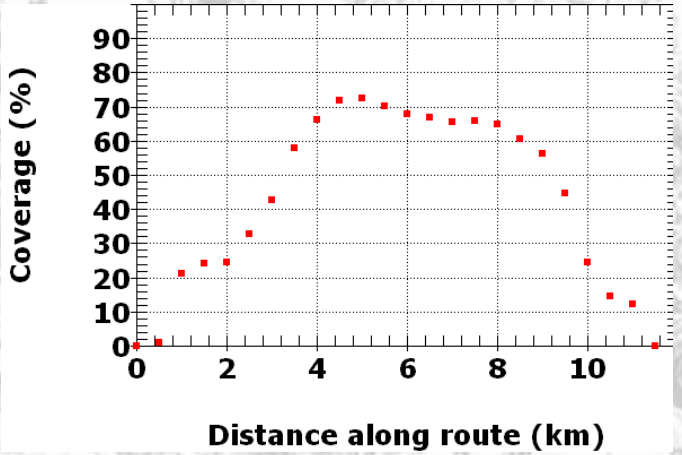


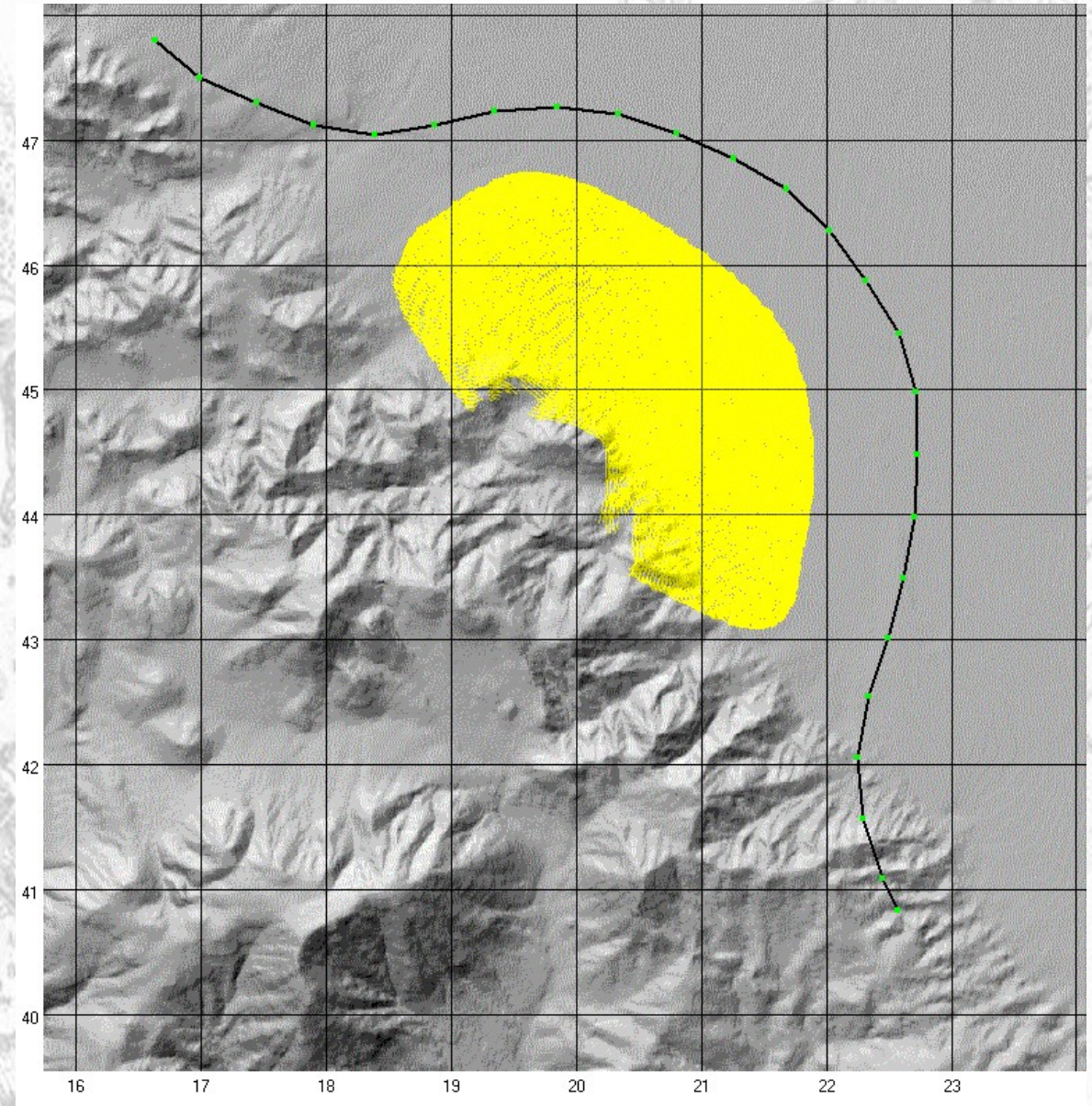


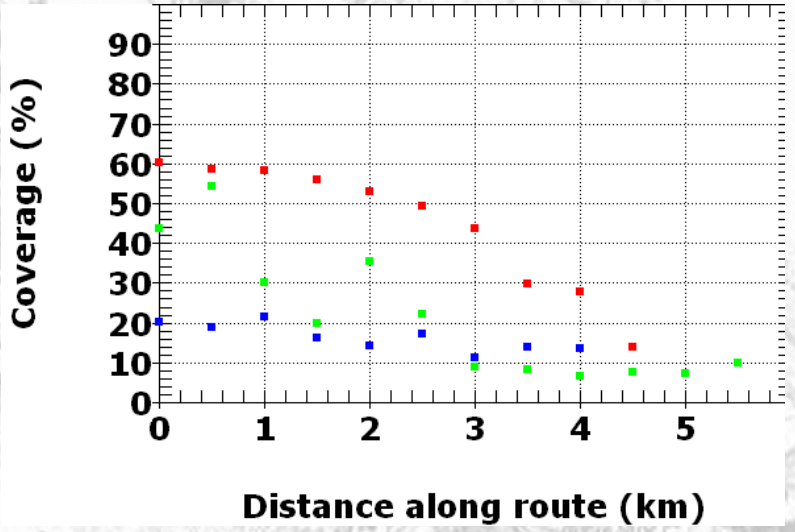


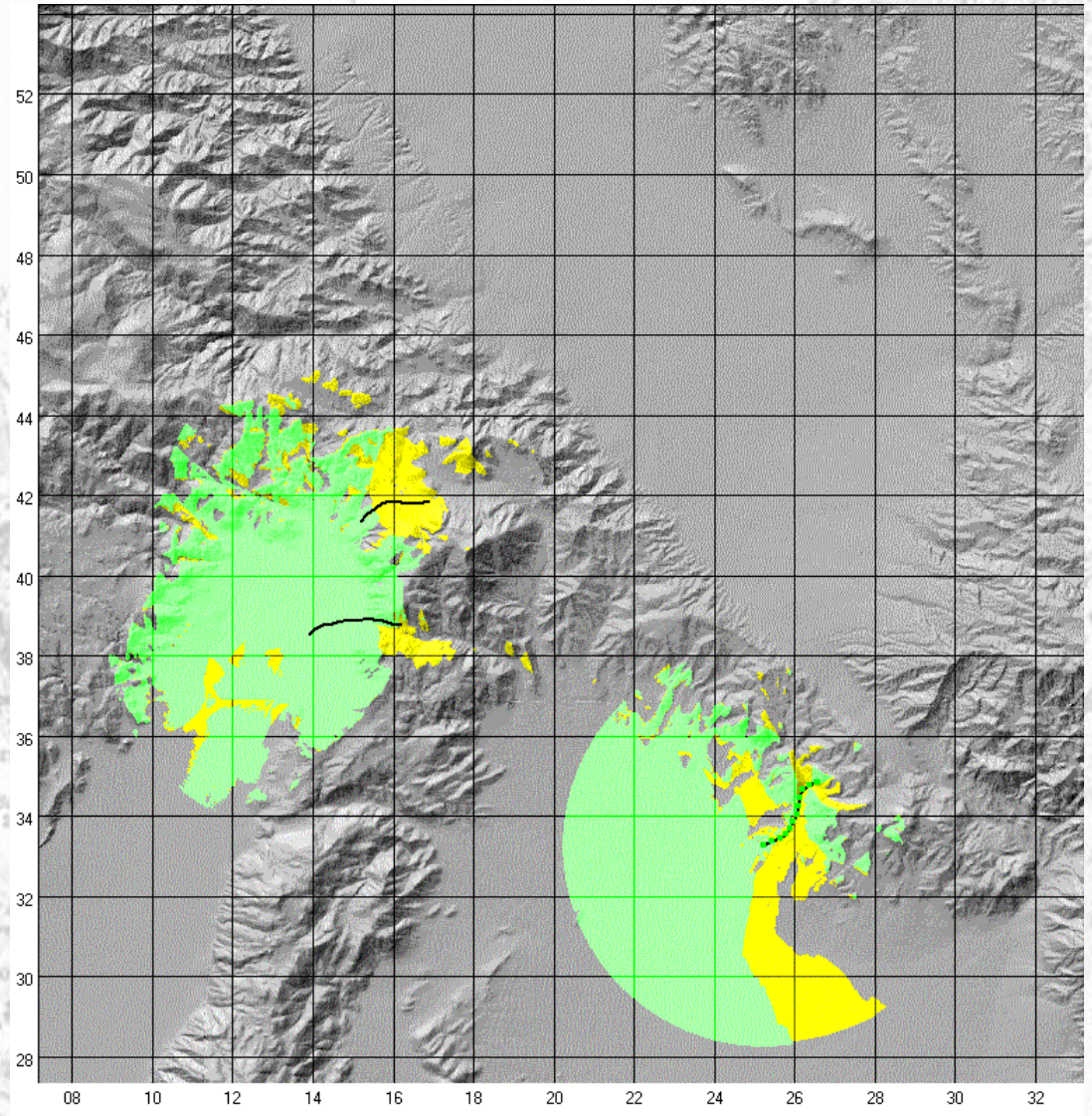


Ambush Movie


Coverage (%)
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
Distance along route (km)


47
46
45
44
43
42
41
40
16
17
18
19
20
21
22
23





Multiple Sensors

- Early prototype
- Coverage each sensor, each time
- User interface key (or automated input)

Urban DEMs and Intervisibility

- Urban DEMs may present different challenges
- Much higher resolution (1 m)
- Much shorter ranges
- May be only UTM
- May have both bare-earth and first return
- Buildings may be separate data structure

Summary

- Viewshed optimization
- Many viewsheds
- How to visualize results—imagine 6000 sensors, compute every minute. What do you need, what do you need saved?